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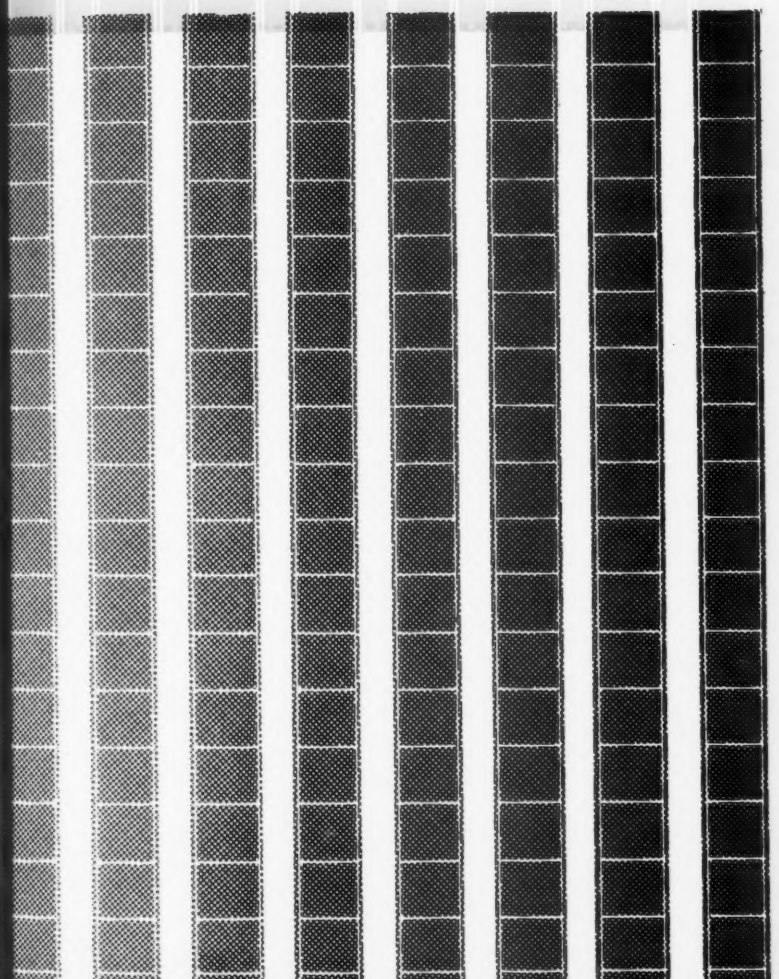

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VOL 4 NO 37 MAY 1959

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SPECIAL FEATURES

The future for ceramics in nuclear reactors
New generations of power reactors will depend on the use of non-metallic fuels. N. C. Moore and J. B. Huffadine of Plessey and Dr. Peter Murray of Harwell combine to tell you what ceramics are, how they are made and how they behave under reactor conditions 86

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under strict control, launching them into the river, towing and hauling out of the river at site was the best answer to the problem.

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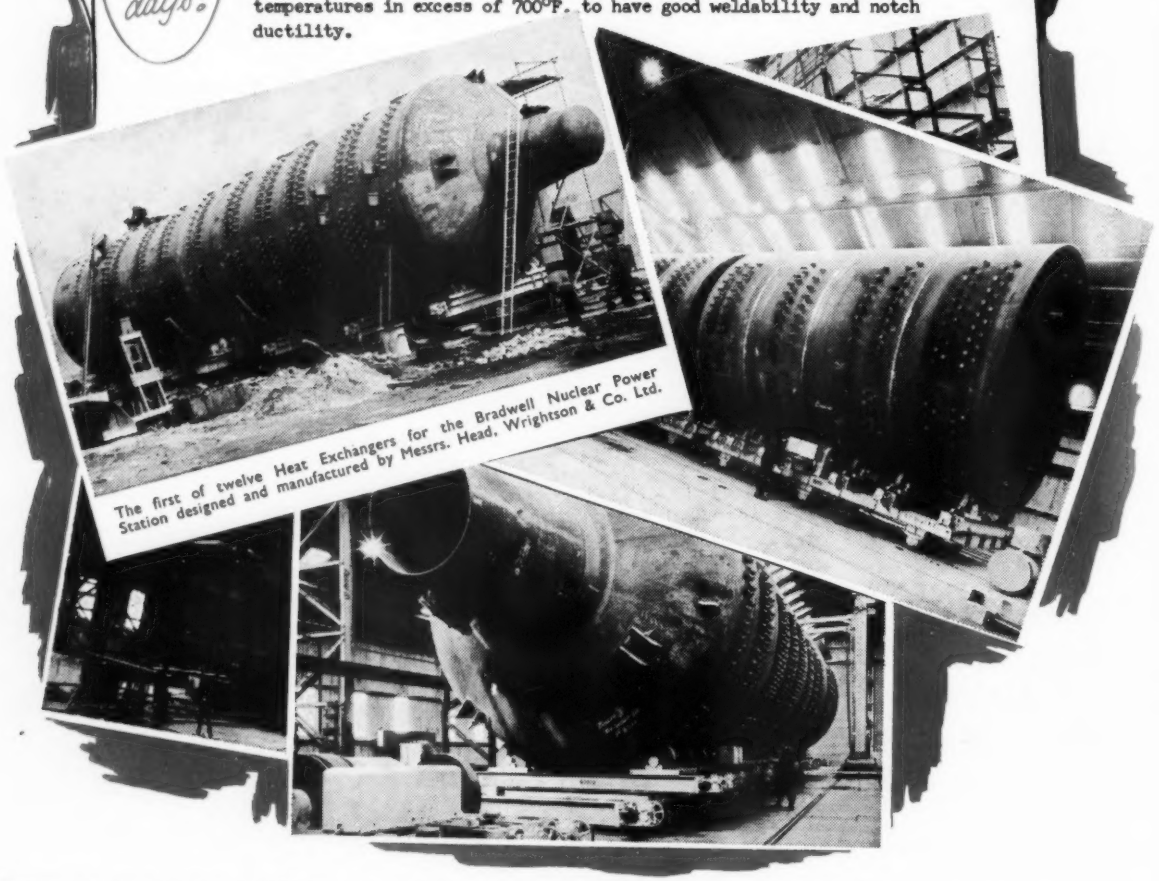

The first of twelve Heat Exchangers for the Bradwell Nuclear Power Station designed and manufactured by Messrs. Head, Wrightson & Co. Ltd.

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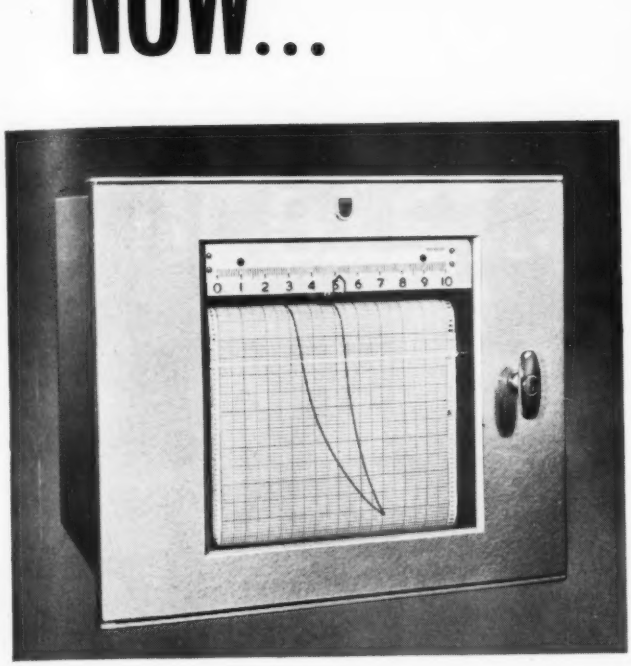

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MEASURING RANGES

Y-CHANNEL	X-CHANNEL
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0..... 10 mV	
0..... 20 mV	0..... 20 mV
0..... 50 mV	0..... 50 mV
0.....100 mV	0.....100 mV
0.....200 mV	0.....200 mV
0.....500 mV	0.....500 mV

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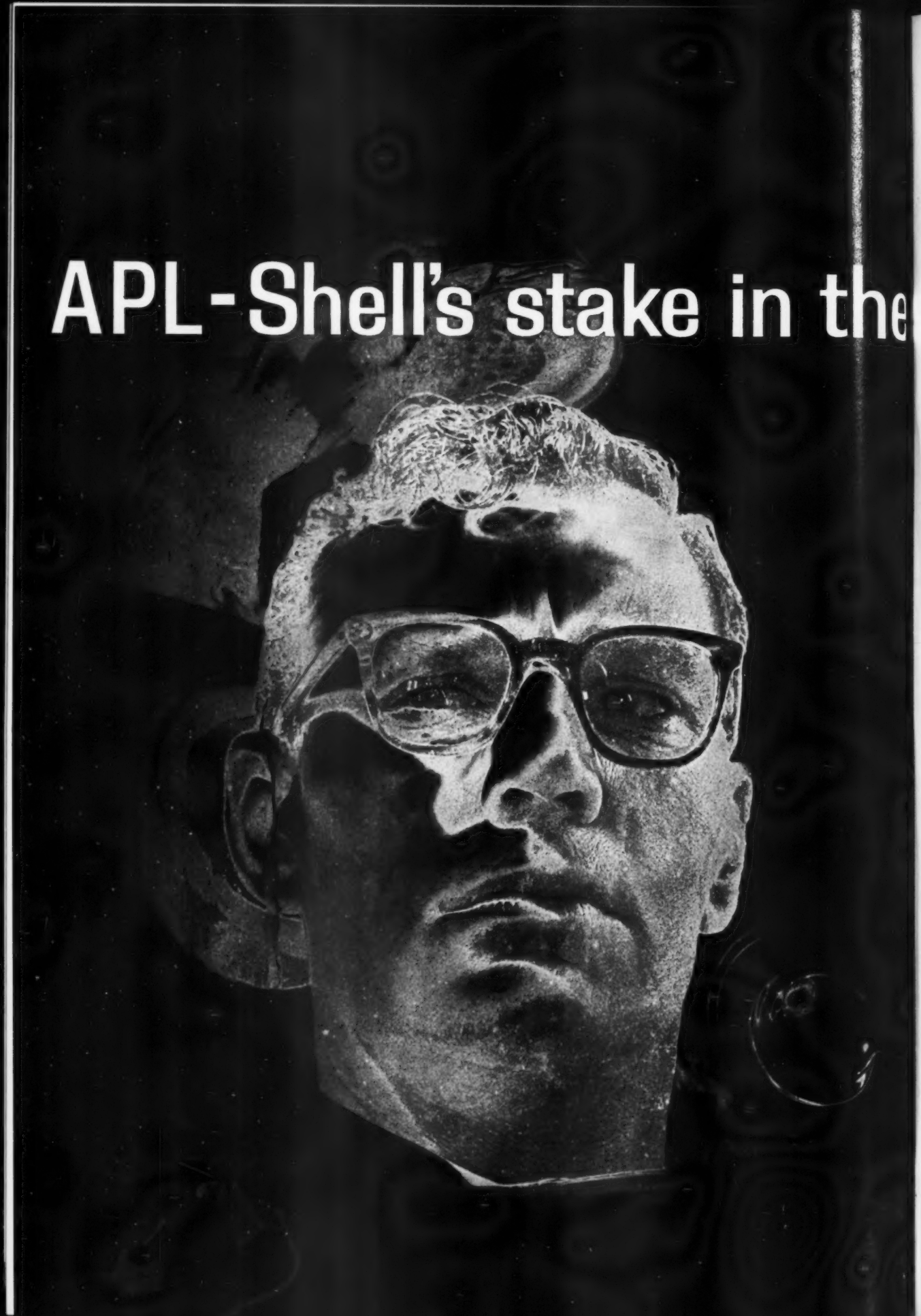

first nuclear decade

To a world hungry for energy, nuclear power brings rich promise. With it, inescapably, come complex new problems which can be mastered only by imaginative thinking.

Conventional lubricants, for instance, are useless when exposed to radiation. They break down, thicken and form harsh solids. Yet the lubricants needed for mechanisms close to the reactor may have to withstand radiation 4 million times stronger than would kill a man. Some of them have to take such punishment continuously for two years or more, for the complicated mechanisms they lubricate cannot be serviced without closing down the reactor altogether – a costly business with plant involving a capital outlay of some £50,000,000.

In 1953, when it was realised that radiation-resistant lubricants were essential, Shell decided to start an extended programme of research. Special groups were set up at Shell's Thornton Research Centre, a generous budget allocated, and their own Cobalt 60 source of radiation installed. Repeated tests took place there and under actual reactor radiation at the United Kingdom Atomic Energy Research Establishment at Harwell.

In 1957 after four years of work the Shell group introduced the world's first range of Atomic Power Lubricants under the brand name of Shell APL – Shell's stake in the first nuclear decade.

Today Shell APL is still the only range of proved radiation-resistant lubricants on the market. Oils and greases from this range, as well as other Shell Industrial Lubricants, are in daily use at many nuclear establishments in the United Kingdom and elsewhere – in lubricating control rod mechanisms, manipulators, electric motors, blower fans and steam turbines. They have also been chosen for the new British atomic power station under construction at Bradwell in Essex.

Here is Shell leadership in lubrication in action – anticipating a need, undertaking fundamental research, and finally developing the products to solve a problem of world-wide importance.

The Research Story

In the hundreds of complex hydrocarbons examined, very different reactions to radiation were observed according to the configuration of the atoms in the molecules. Highly complex structures of an entirely different nature from the original material were formed. Following extensive experiments, the Shell APL range of lubricants was developed and proved. Included are such oils as Shell APL 729 mainly for use in blowers. This oil now has a performance equal to a good quality modern turbine oil. Shell APL 700 series greases have been tested in bearings operated within the BEPO reactor and subjected to CO_2 gas under pressure at 150°C. After receiving a total dosage of 2.7×10^{18} thermal neutrons plus associated radiation, the grease and bearings were found to be still in good condition.

Other lines of research include the latest developments in the use of radio-active isotopes in the measurement of wear. Recent results have been published in a paper presented at the 1958 Geneva Conference, a further example of the work continually being undertaken by the Shell group to assist industry.

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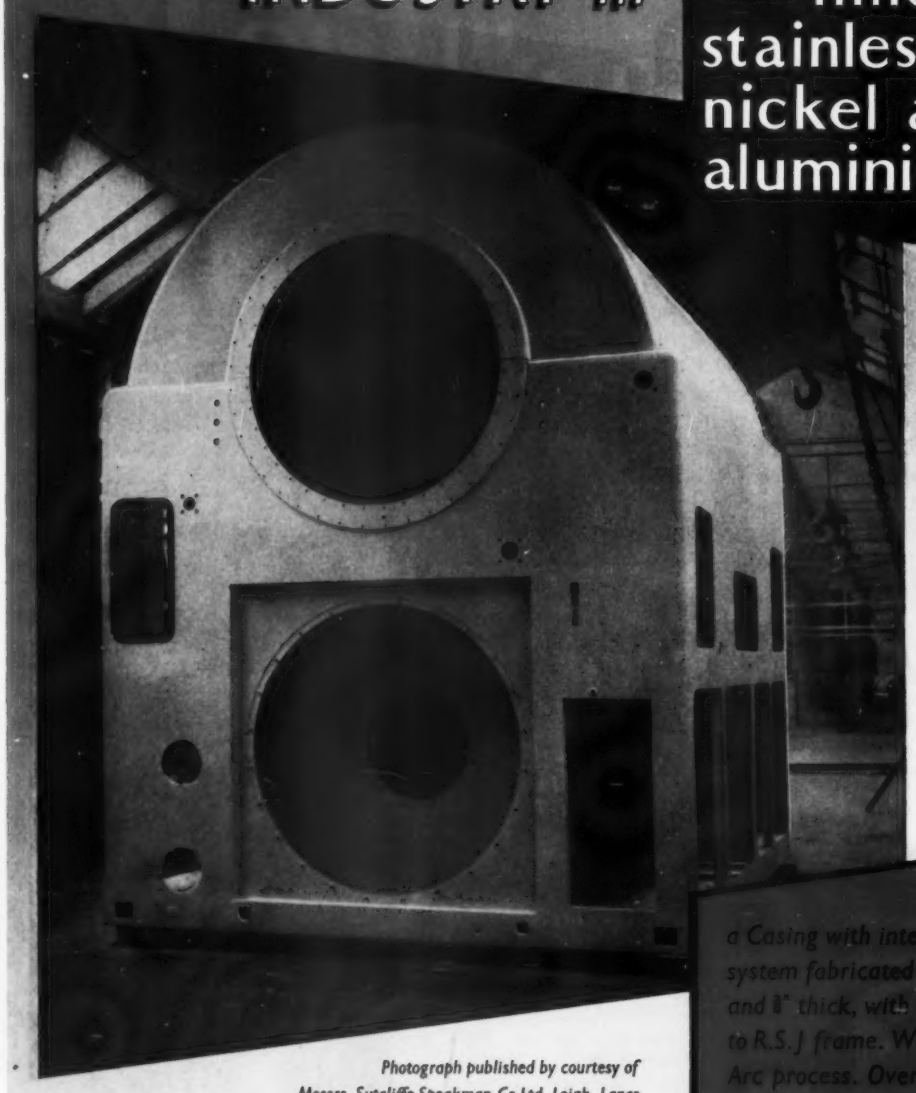

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Illustration shows a Casing with internal baffle and fan system fabricated in mild steel ⅜", ¼" and ⅛" thick, with base sheets welded to R.S.J frame. Welded by Metallic-Arc process. Overall Dimensions approx: 12' long x 8' wide x 12' high Weight 7 tons.

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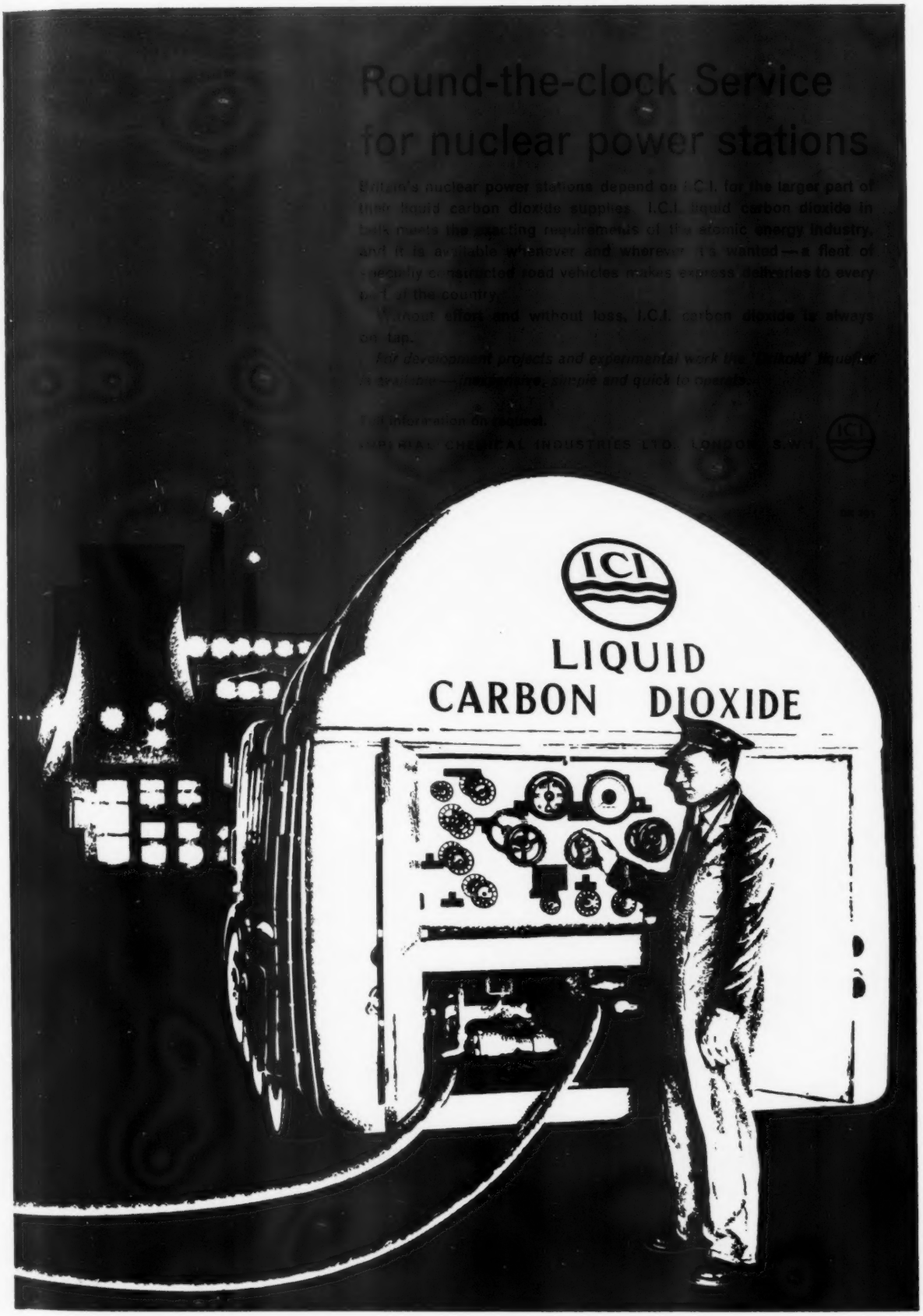

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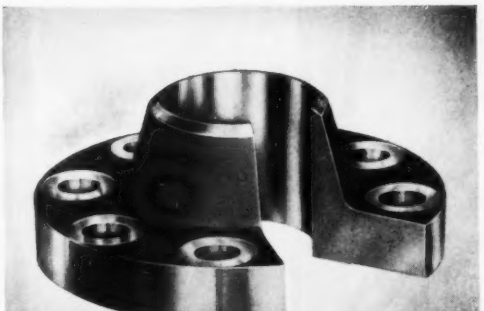

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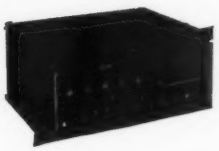

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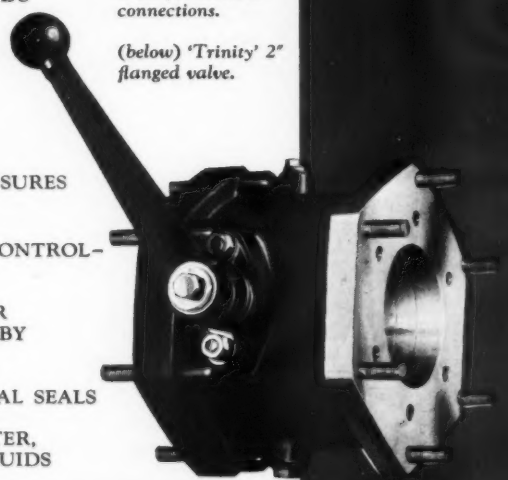

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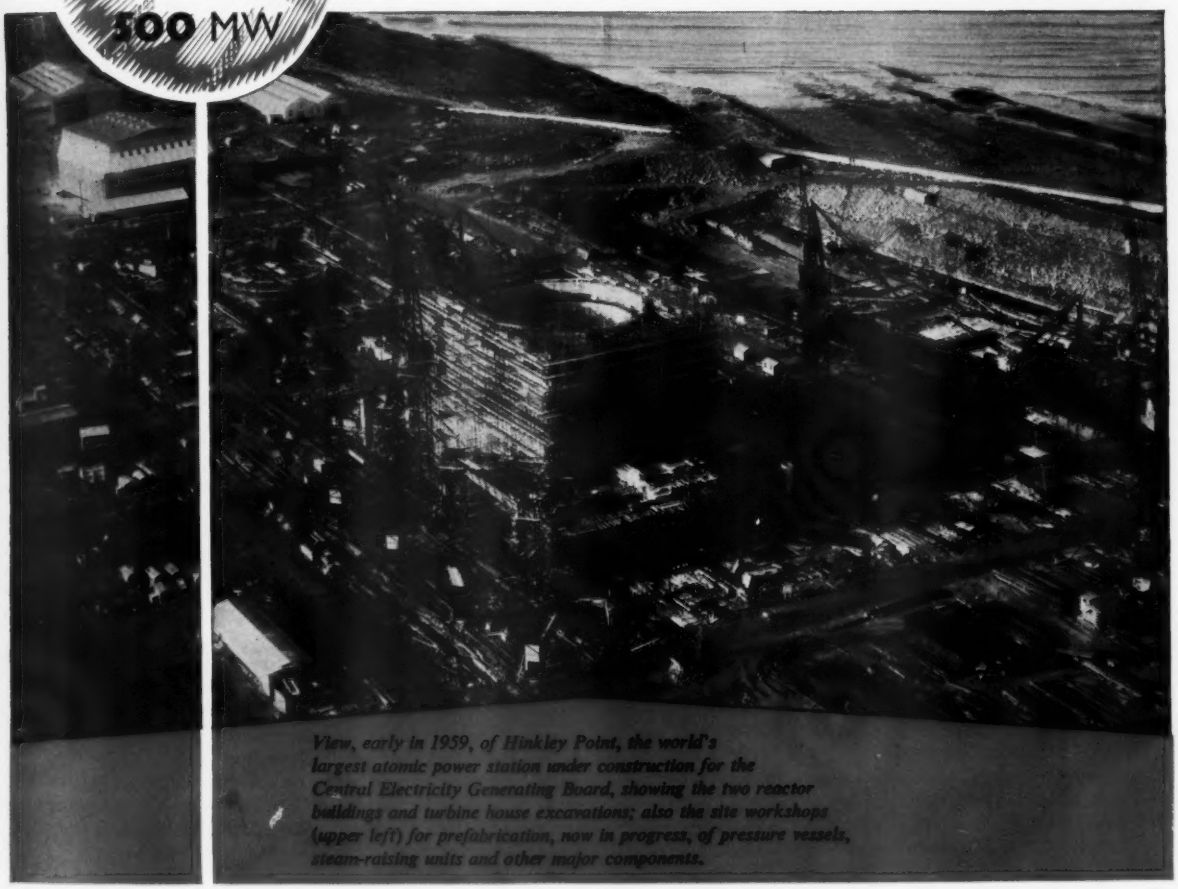

View, early in 1959, of Hinkley Point, the world's largest atomic power station under construction for the Central Electricity Generating Board, showing the two reactor buildings and turbine house excavations; also the site workshops (upper left) for prefabrication, now in progress, of pressure vessels, steam-raising units and other major components.

150 MW

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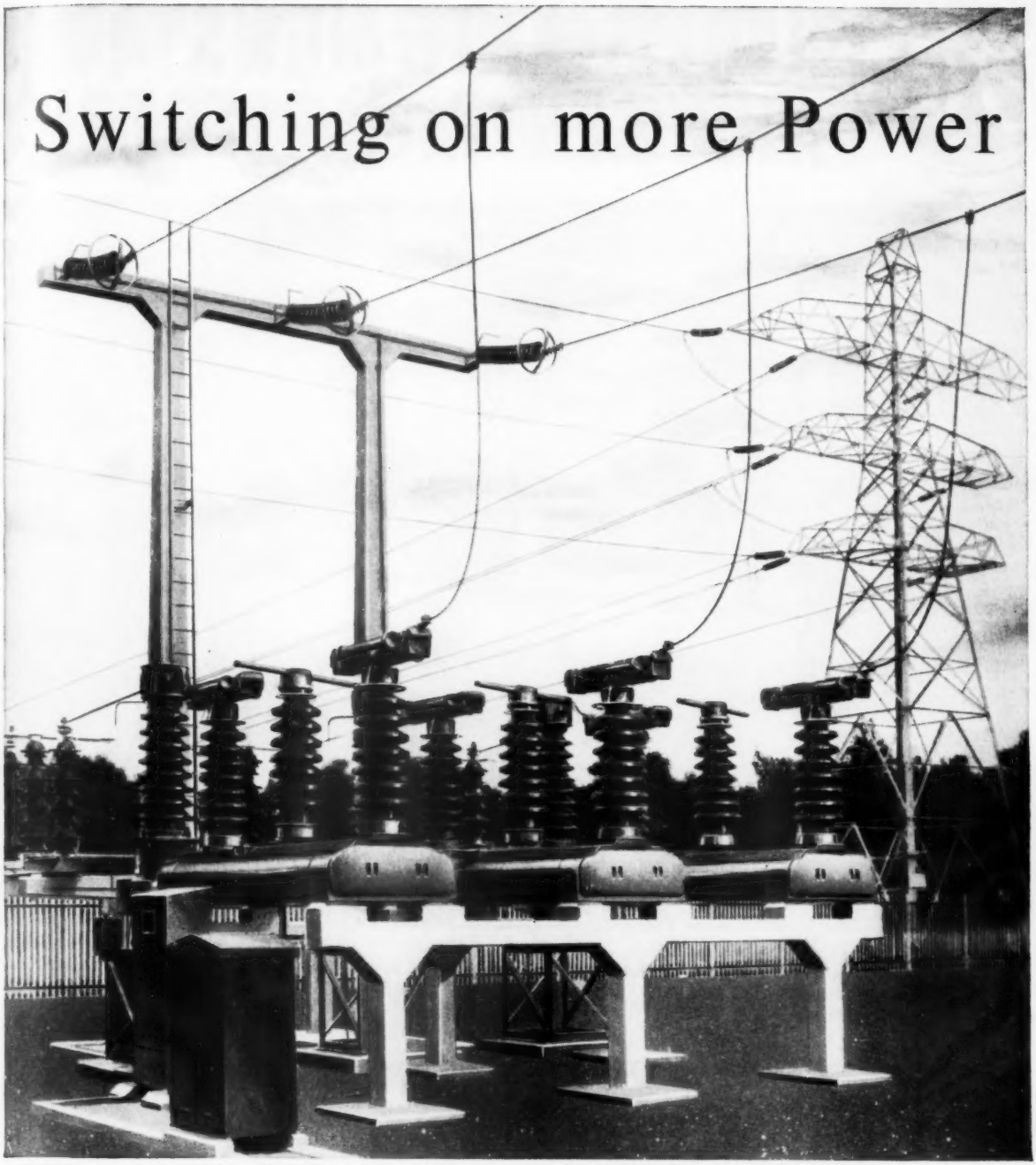


The photograph shows a Metrovick 132 *kV.*, 3,500 *MVA., Type GA6W4 Air-Blast Circuit Breaker installed in a British substation*

This type of breaker is in extensive use on the British grid system, and has been selected to control the output of Scotland's first Nuclear Power Station at Hunterston. Overseas, 132kV., 5000-MVA., Type GA6W4 breakers will be installed in seven new sub-stations in the Greater Buenos Aires area of Argentina.

METROPOLITAN-VICKERS
ELECTRICAL CO LTD · TRAFFORD PARK · MANCHESTER 17

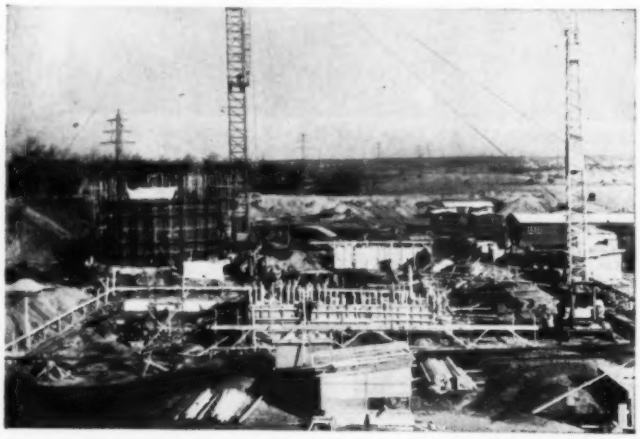
An A.E.I. Company

F/A901

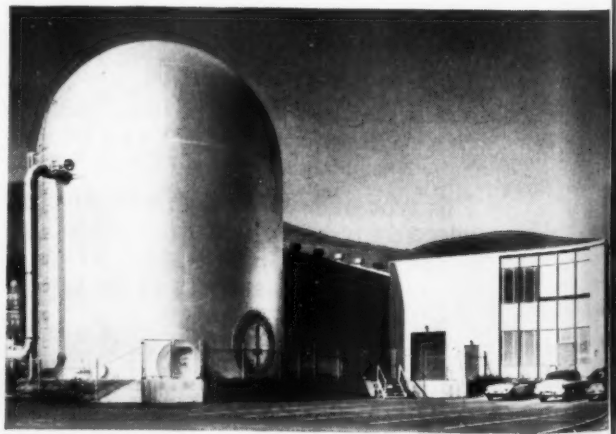
From all over the world...

HERE'S LATE NEWS ABOUT AND GENERAL ELECTRIC'S

Rome, Italy. A 150,000 kw (e) atomic power plant like the one shown in this sketch will be built by General Electric for the Societa Elettronucleare Nazionale (SENN) of Italy. The plant will utilize a G-E dual-cycle boiling water reactor and will be located at Punta Fiume near Naples. The design of the plant contemplates a possible future increase of kilowatt output without substantial reactor equipment changes. Construction of the plant is expected to get underway later this year with completion planned for early 1963.



Frankfurt, Germany. RWE, one of Europe's largest utility companies, announced that construction had begun on the country's first nuclear power Station. G. E. will supply the nuclear reactor steam supply system which includes a 15,000 kw (e) BWR. It is scheduled for operation late in 1960.



Pleasanton, California. Since October 1957, the Pacific Gas and Electric Company has been distributing 5,000 kw (e) of electric power produced in the General Electric Vallecitos Boiling Water Reactor plant. Pleased with results of this, PG & E recently ordered a 50,000 kw (e) reactor from General Electric.

IMPORTANT ATOMIC PROJECTS
BOILING WATER REACTOR

Low power costs and extensive operating experience combine to make General Electric's BWR the leader among current reactor concepts

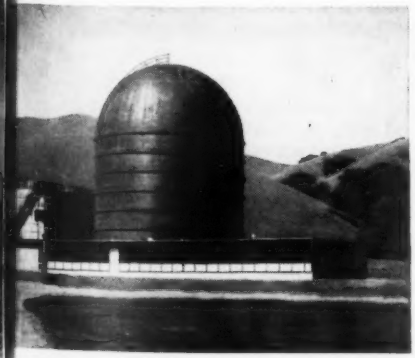
Recently, the Societa Elettro-nucleare Nazionale (SENN) of Italy announced the award to International General Electric for its 150,000 kw nuclear power plant. SENN's decision came after a seven man international team of nuclear experts analyzed the reactor proposals offered by nine groups. The award was based on SENN's evaluation showing that the G-E boiling water reactor would provide the lowest power costs of all the current reactor concepts. This is the result of two G-E achievements: (1) the system simplicity of the BWR developed by General Electric, makes low capital costs possible, and (2) advanced research and development on the design and manufacture of oxide fuel elements enables G. E. to offer a high fuel burnup guarantee. These two things combined with General Electric's actual BWR operating experience are the important reasons behind the great interest electric utilities throughout the world are showing in G. E.'s large boiling water reactors.

General Electric's extensive atomic facilities in California are ready now to help you with the application and technical advancement of atomic energy. For further information contact our Geneva office or write: *International General Electric Company, Dept. 59-93, 150 East 42nd Street, New York 17, New York, U. S. A.*

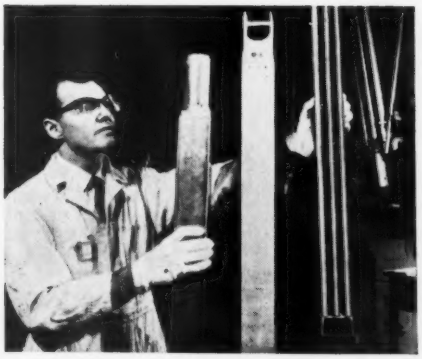
Late Bulletin! Soon after this report was prepared, it was announced that the International General Electric Company had received the award for a 12,500 kw nuclear power station from the Japan Atomic Research Institute (JAERI). This plant is scheduled to be the first nuclear power electric generating plant to be placed into operation in the Far East. For full details about this and other developments see the next G-E report in this publication.

GENERAL ELECTRIC
— U. S. A. —

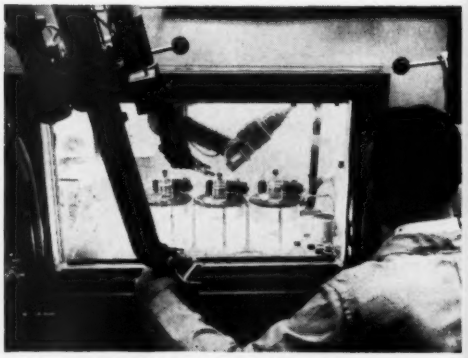
Chicago, Illinois. The 180,000 kw (e) Commonwealth Edison Dresden Nuclear Power Station (photo above) is nearing completion—six months ahead of schedule. It will use the dual-cycle boiling water reactor and is another example of General Electric's contribution toward economical nuclear power.



G. E.'s 30,000 kw (t) Test Reactor went critical in December, 1958, substantially increasing facilities for the vital testing of materials under intense nuclear irradiations. Interested organizations are being offered irradiation service in the GETR.



General Electric manufactures rod-type and plate-type fuel elements for many power and research reactors. A mechanized production line for rod-type elements covers powder and pellet processing, autoclaving and testing stages, and allows rigid quality control.



G. E.'s Laboratory Services include the Radioactive Materials Laboratory which performs extensive post-irradiation examinations. Personnel with thousands of man-years of experience contribute to G. E.'s leadership in advancing commercial uses of atomic energy.

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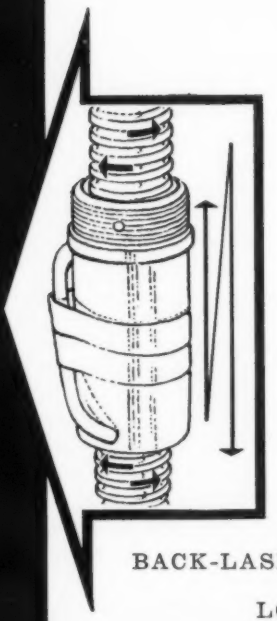
Bristol Siddeley provide a comprehensive range of high precision recirculating ball and lead screws and splines for universal applications.



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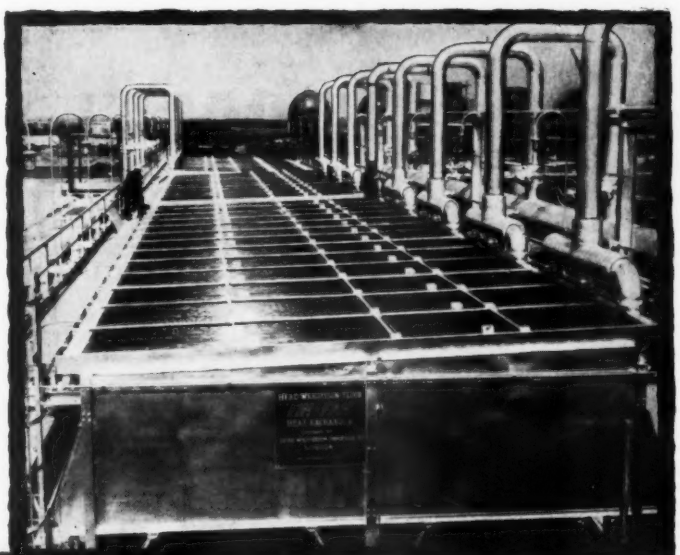

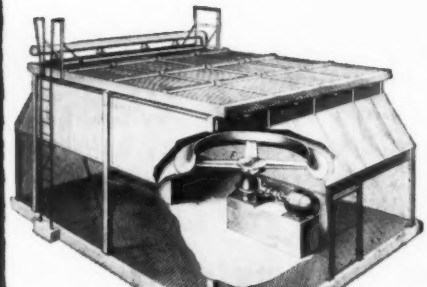

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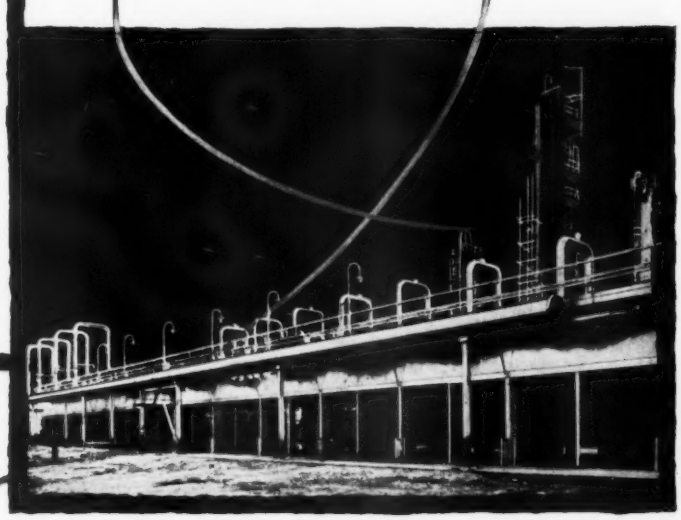

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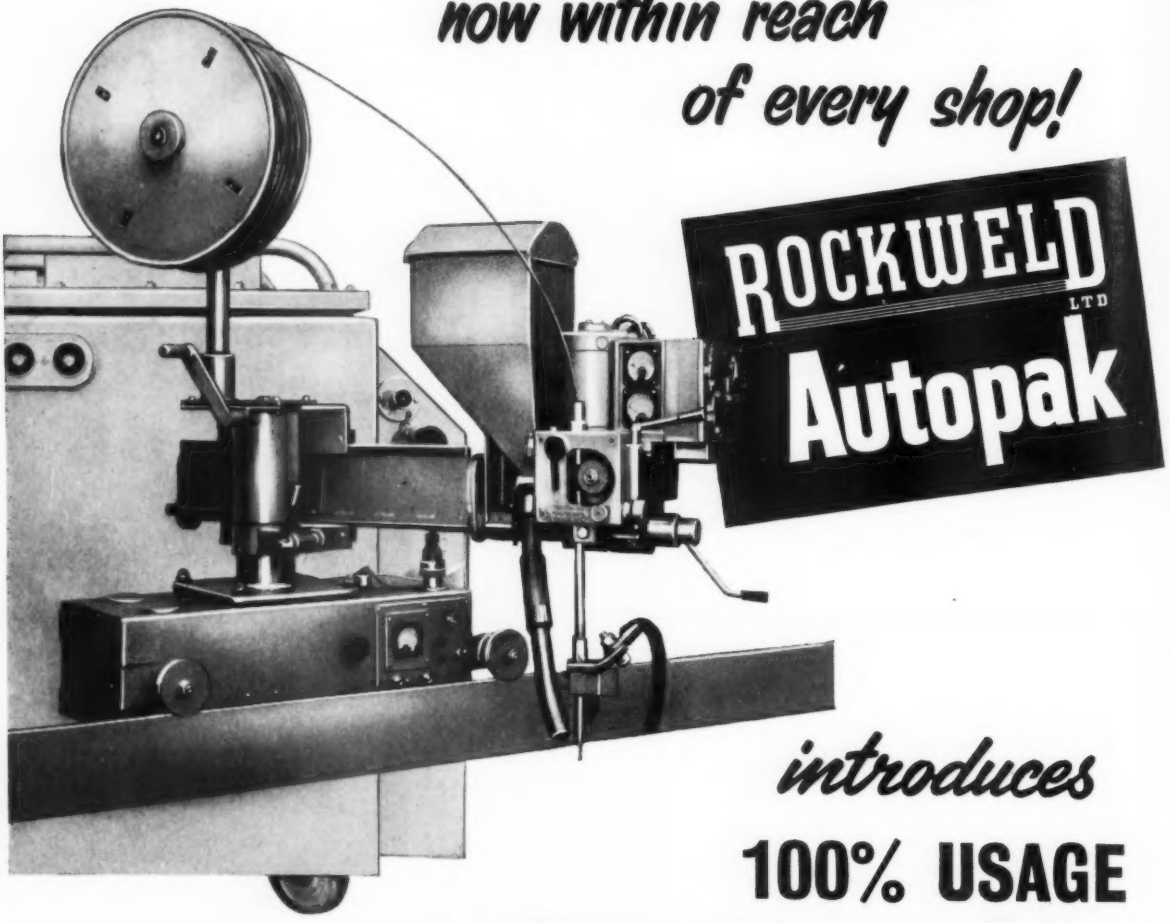

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2 IMPORTANT DEMINERALISATION PLANTS

William Boby & Co. Ltd. have been entrusted with the execution of the demineralisation water treatment plants at:

1 CHEMSTRAND LTD., N. Ireland

(Main Contractors: Messrs. Constructors John Brown)

For their new 'ACRILAN' factory at Coleraine, N. Ireland, Messrs. Chemstrand have installed a 10,000 galls./hr. 'Boby' demineralisation plant for process and boiler feed water.

The plant comprises the following sections:

Coagulation and Settlement — Filtration — Cation Exchange — Weakly basic Anion Exchange — Degassing — Mixed Bed Ion Exchange.

2 VEITSILUOTO O/Y, Finland

The Veitsiluoto paper mills of Finland have installed a 13,400 galls/hr. 'Boby' demineralisation water treatment plant for feed water for boiler working at 1,750 p.s.i.

The plant comprises the following sections:

Coagulation and Settlement—Filtration—Cation Exchange —Weakly basic Anion Exchange — Strongly basic Anion Exchange.

WATER BOBY TREATMENT

Established in 1875

WILLIAM BOBY & CO. LTD.

RICKMANSWORTH, HERTFORDSHIRE, ENGLAND. Telephone: Rickmansworth 4251*

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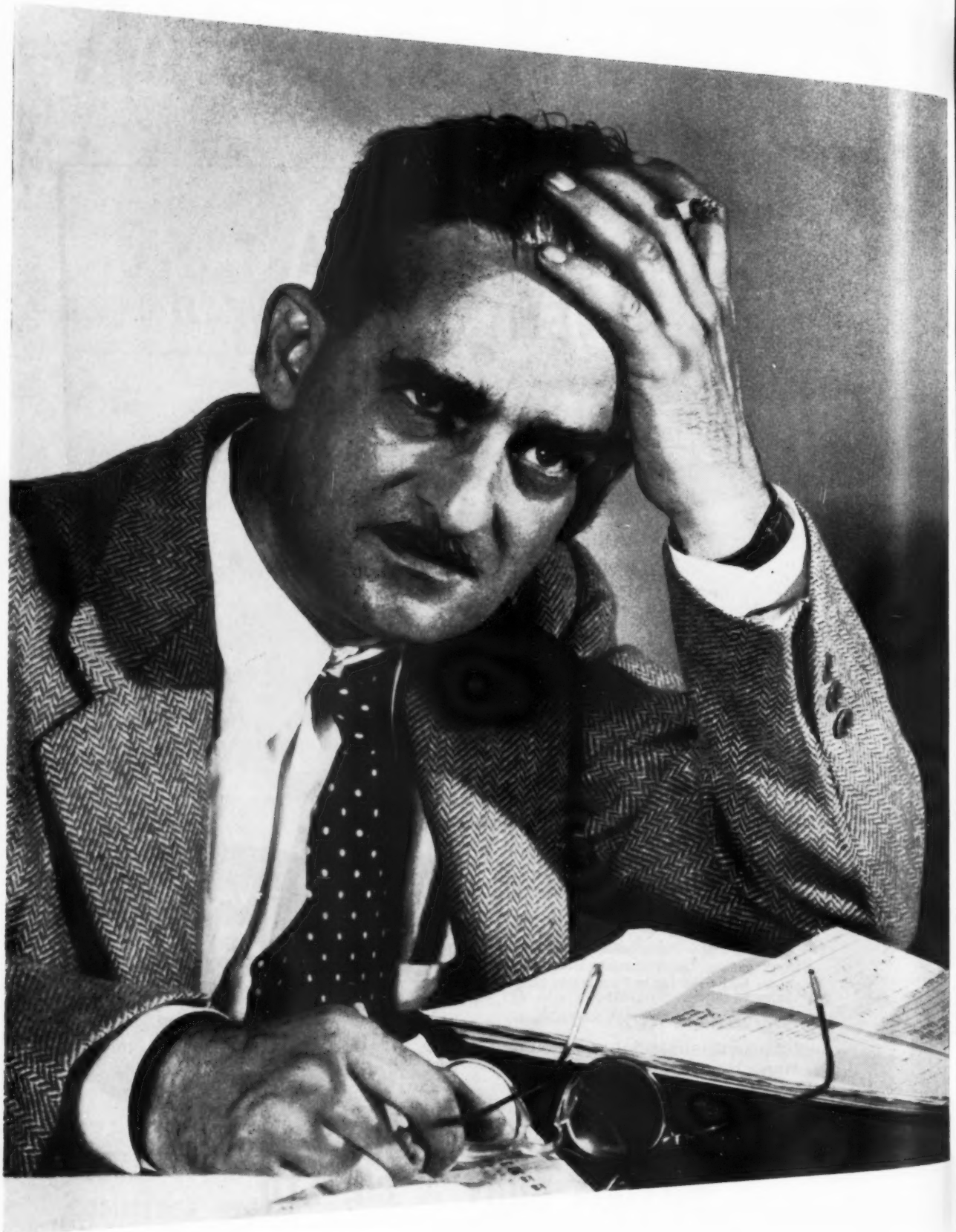

CFW/V4

"O.K.– Let's call it a day"

" I've done my best—I can't do more. I've saved this firm hundreds of pounds by fuel economies in the last few years. I've never missed a trick. But still fuel costs keep going up and spoiling the picture. I've had enough. It's more than flesh and blood can stand. I'm through . . ."

Just a minute, Sir. Before you leave us for good—isn't there one trick you're missing? You haven't put in VERSIL Glass Fibre insulation yet, have you? That means you don't yet know what really efficient insulation, complete insulation, can do for you. May we show you? It'll brighten things up for you considerably. You might even recover the will to live! Just write to VERSIL Ltd., Rayner Mills, Liversedge, Yorkshire. Telephone Cleckheaton 2571/3.

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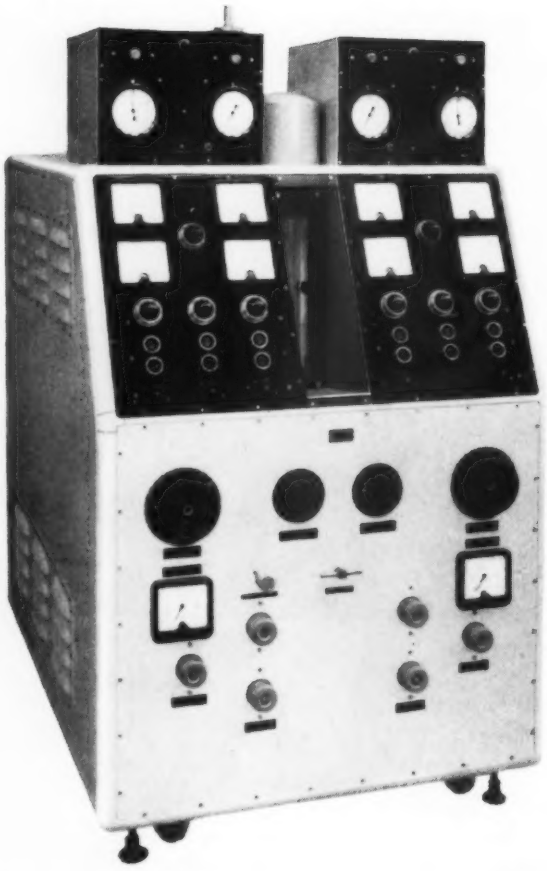

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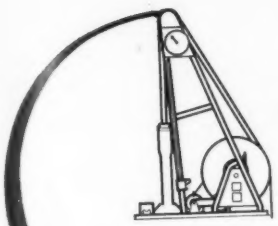


PYE

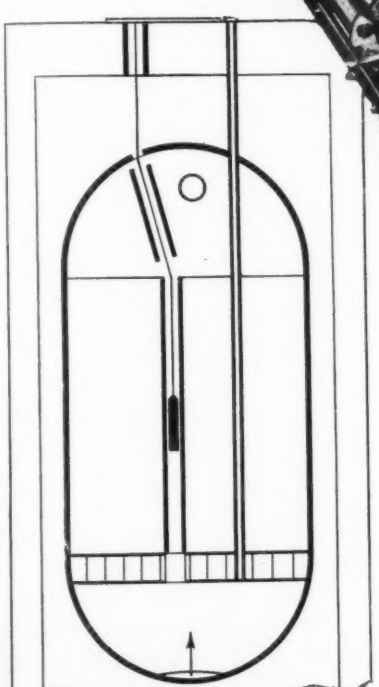
REACTOR INSPECTION TELEVISION EQUIPMENT

REACTOR CAMERA

Television is a vital technique in the operation of gas-cooled reactors. The type of camera shown is in regular use at Calder Hall Nuclear Power Station, England; it carries its own lighting, and, in addition to visual inspection of the reactor interior, permits the removal of objects from the reactor using the special grab attachments. All the camera facilities are controlled remotely.

The camera functions satisfactorily with radiation dose rates greater than 10^5 Rads. per hour; cooling gas, carried to the camera by the supporting hose, allows operation with ambient temperature of 150°C.

Direct experience of such conditions over a number of years has enabled Pye to design cameras that will withstand high levels of nuclear radiation, temperature and pressure. Models can be supplied for use in water-cooled reactors. If you have any specialised television requirements, contact Pye Ltd., and avail yourself of their experience.



This console gives complete remote control of the camera. It carries the picture monitor and the control unit.

PYE LIMITED · ATOMICS DIVISION · CAMBRIDGE · ENGLAND

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another problem solved with UNISTRUT

INSTALLING INSTRUMENTATION AT AUTOMATED "SEGAS" OIL GASIFICATION PLANT

Three men and a computer control the production of 20 million cubic feet a day of town gas at Britain's first large-scale oil gasification plant. South Eastern Gas Board engineers faced an unusually complex problem in installing the instrumentation network essential for such a high degree of automation.

Unistrut steel channel framing and a pipe cable clamp from the comprehensive range of Unistrut fittings gave the satisfactory solution, with the following advantages . . .

Accurate routing

9½ miles of service pipes—hydraulic, air, electric and instrumentation—run from all parts of the £2½ million plant to the central control room traversing a 253 ft. long covered cable bridge with a drop of 20 ft. at each end. Each pipe has to be precisely located in relation to the control panel and computer and any slight positional errors in erection would be considerably magnified over runs of up to 500 ft. By using Unistrut, in which the position of every fitting is infinitely adjustable before and after attachment, accurate positioning was made possible.

Ease of access

The pipes run through the cable bridge on five 8 ft. high Unistrut racks, four of which are double banked, the five rows of vertical supports being connected at the top to complete the box section and their bases slot-clamped to a horizontal Unistrut channel to allow for heat expansion. Further Unistrut framing carries the pipes to the control room floor where they are attached by clips to Unistrut channels.

In a plan of this type it is of course essential that all servicing be carried out with minimum delay. A false floor of Unistrut beams on which are laid 5′ x 2′ nominal size panels of rubber covered plywood gives immediate access.

Exterior use

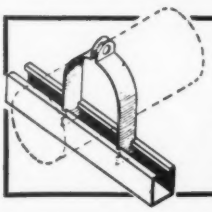
Galvanised Unistrut, available as an alternative to the standard stove-enamelled finish, was used for the trusses supporting the pipes in the open between the gasification units and cable bridge.

Erection economies

Welding and drilling, which would have represented a considerable expense in using conventional support methods for a project of this scale, were eliminated by Unistrut's rapid, self-locating nut assembly. This standardised method was used to form all the framing, in which 10,600 feet of Unistrut were used, and adds to the basic strength of the cold-rolled steel channel by completing a rigid box-section.

Further economies were realised in running the pipes, by using the clip-in fitting shown below, which obviated the need to mark out in advance the precise position of each point of attachment.

This application illustrates some of the on-site advantages of the Unistrut steel-channel framing system, including the fast and economical erection of rigid structures and rapid attachment of services. It cannot however indicate the full scope of the system, which includes a full range of components for supporting every type of service. For further information, please write to the address below.



The Unistrut clamp employed throughout this installation typifies the economy of material and effort derived from the Unistrut's special channel section. The two parts of the clamp are located by cut-out lugs against the inside of the channel, so that a single screw and nut is all that is necessary to fasten or release the assembly. (For larger pipes, flanged clamps or rollers are used, bolted to self-locating nuts inserted at the desired point of the continuous-entry channel.)

UNISTRUT

STEEL CHANNEL FRAMING SYSTEM

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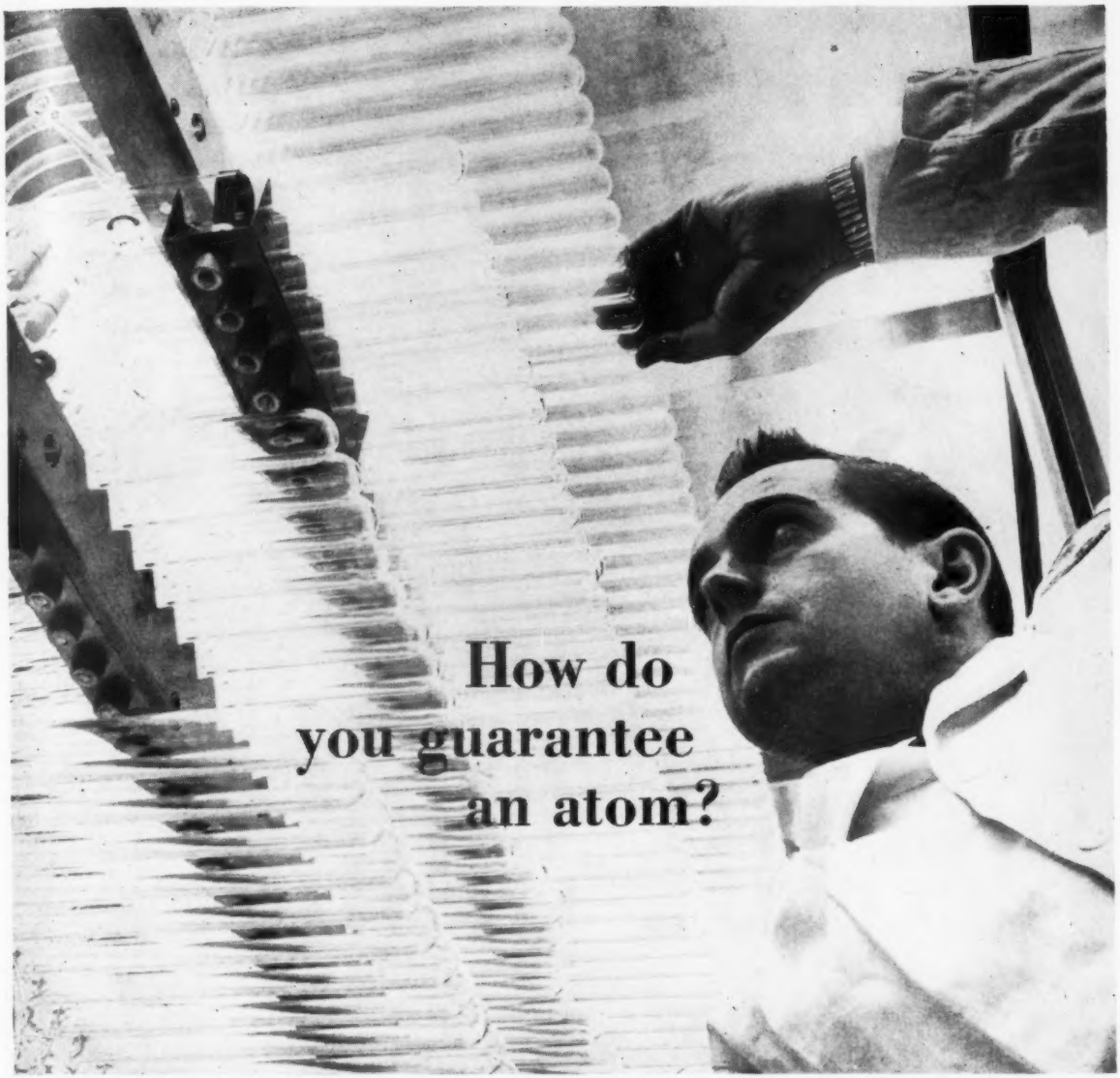

Atomics International technician with countercurrent distribution apparatus used to study moderator-coolant for Organic Power Reactor.

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Outstanding advantages of the ORGANIC POWER REACTOR: Low capital investment • Low cost operation • High inherent safety and flexibility • Reliability resulting from

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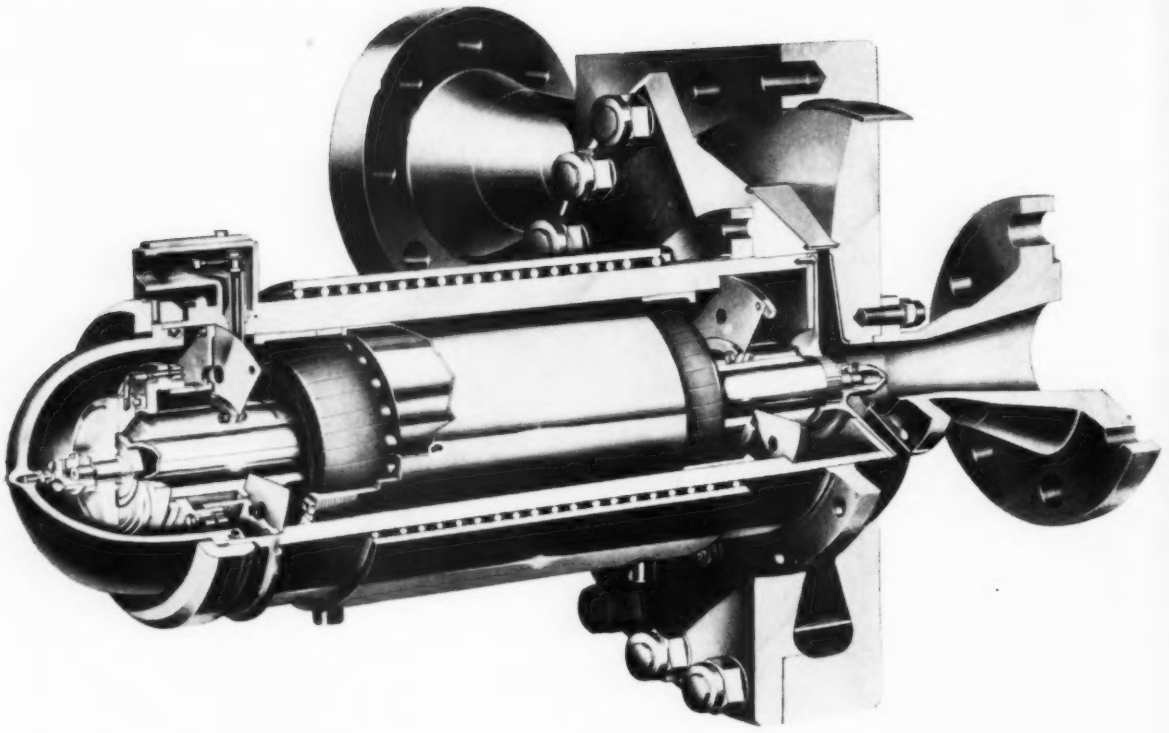

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They are:

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THE AUTHORITY ON SUPERHEATED STEAM

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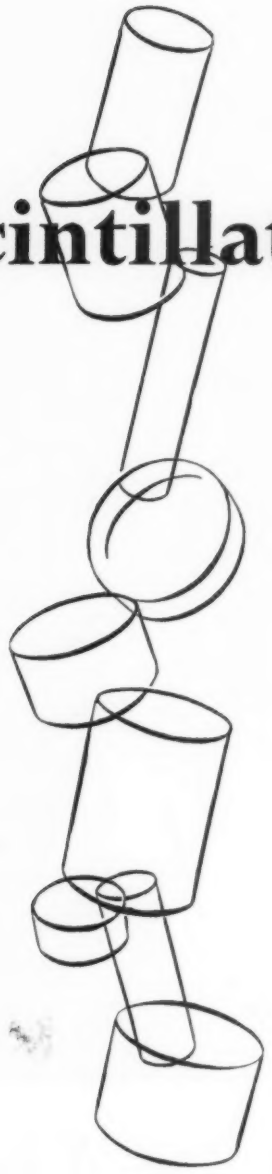

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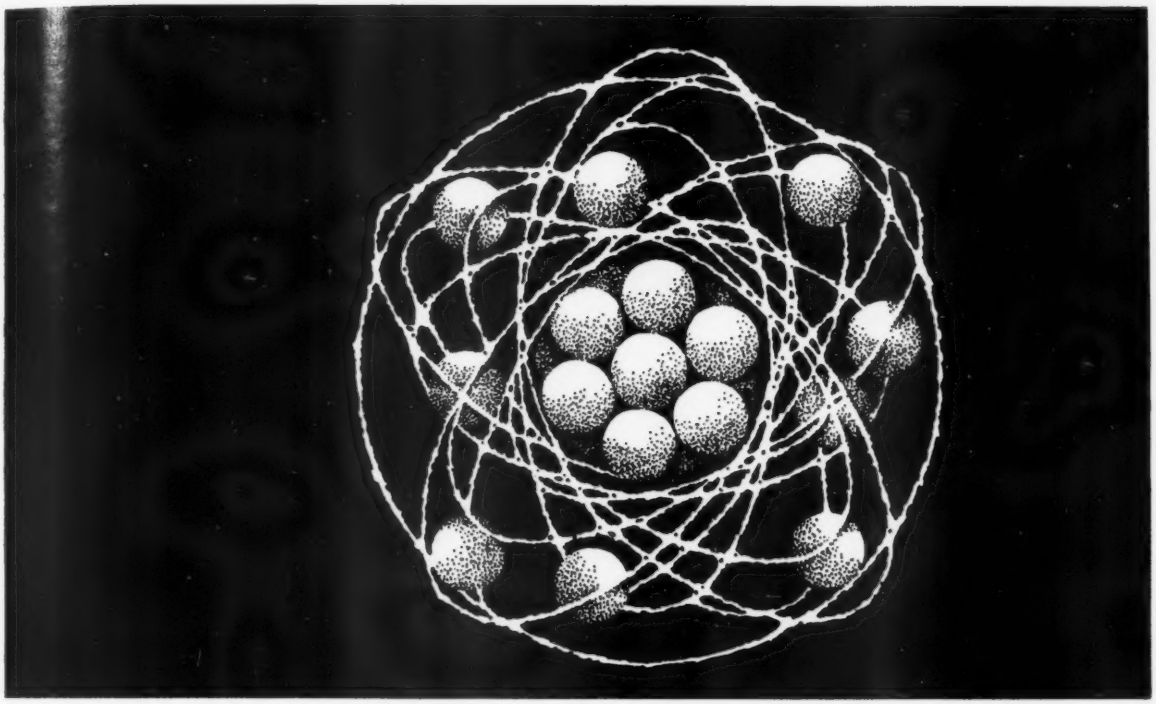

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External means are used in order to urge the disc sealing ring on to or away from the valve seat for closing or opening the valve. Operation can be effected according to requirements by hand, electric, pneumatic and hydraulic means.

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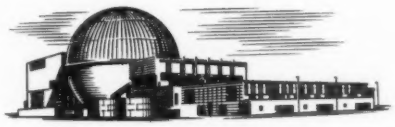

The Pyrene Company, with its unrivalled facilities for research, keeps ahead of changing industrial techniques, and is constantly developing the means to overcome the new fire risks they involve. As makers of the world's most comprehensive range of fire-fighting equipment, The Pyrene Company can give you invaluable and impartial advice on any fire protection problem—it is yours for the asking.

We are proud to have given advice on fire protection—and supplied major fire-fighting equipment—for most British atomic centres already constructed. Consult Pyrene Fire Engineers and ensure maximum fire protection for valuable plant and human lives too.

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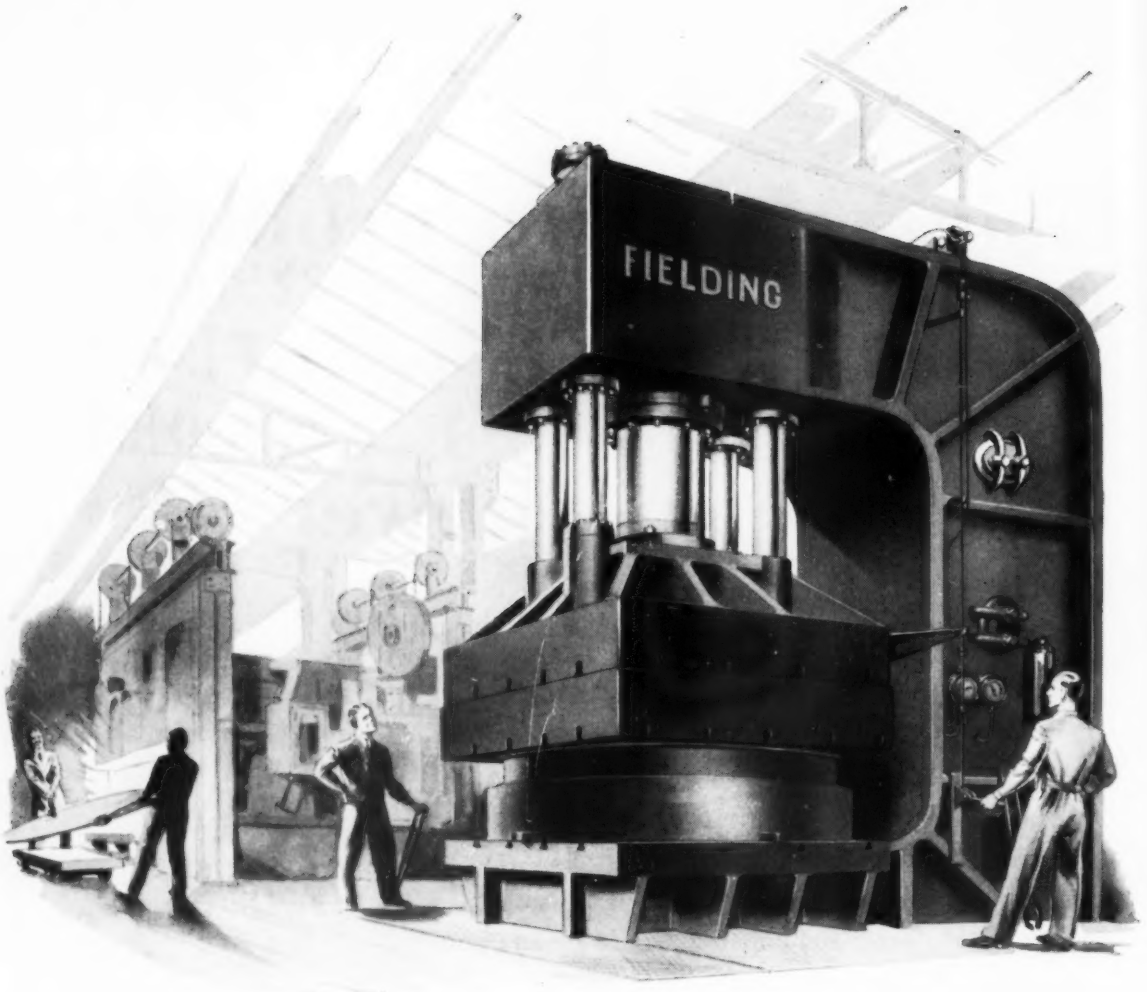

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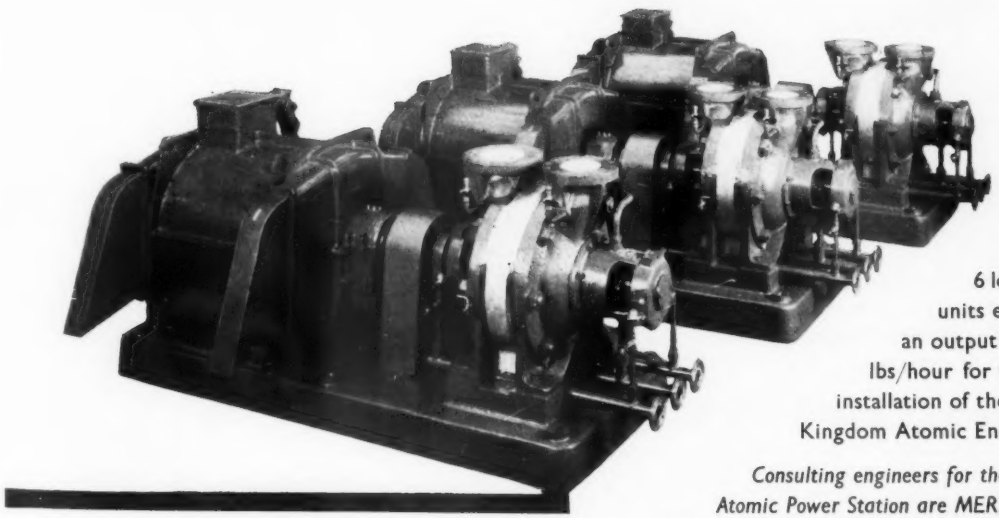
Model showing Chapelcross power station

SULZER

BOILER FEED PUMPS FOR NUCLEAR POWER STATIONS



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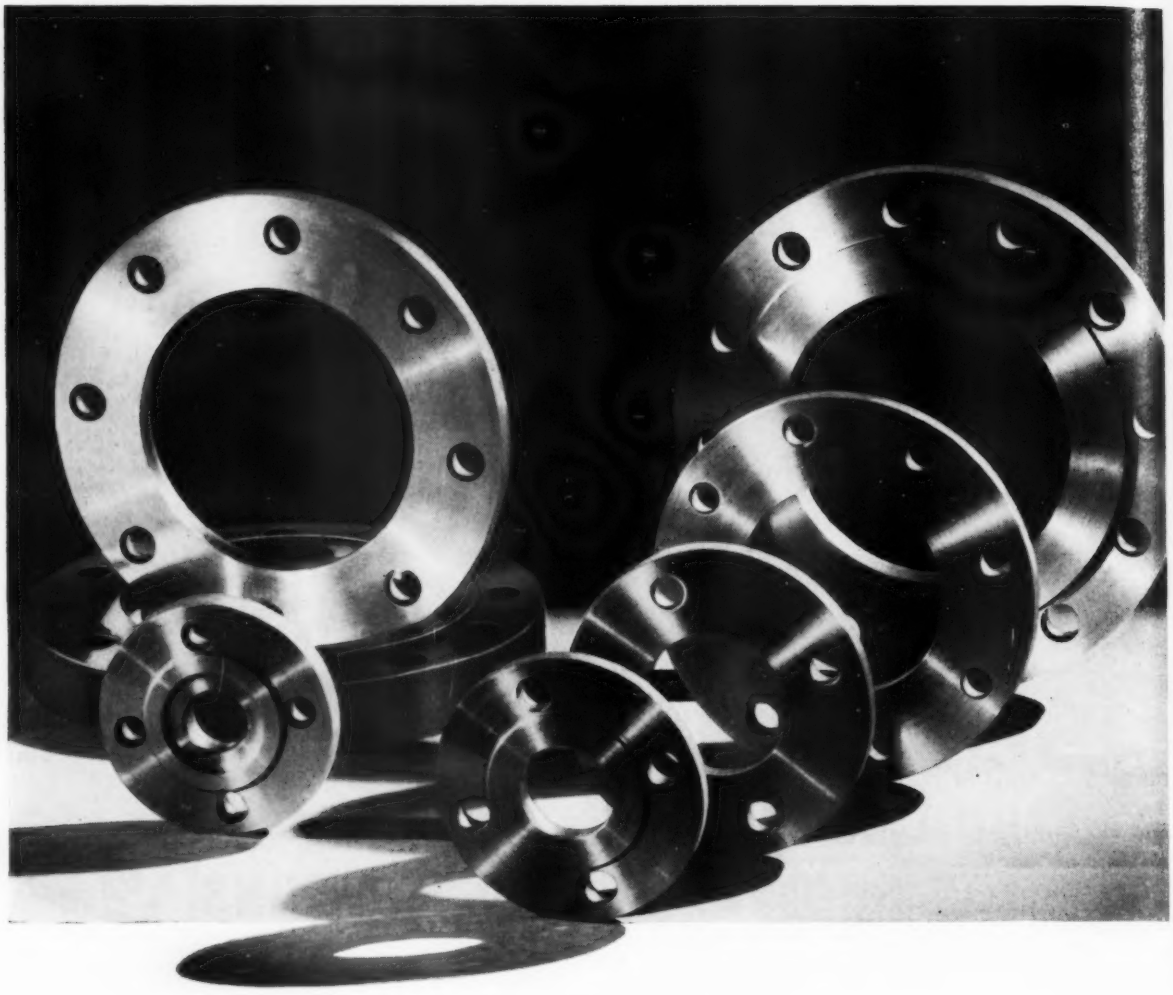

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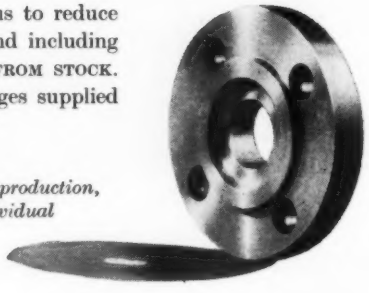

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E.2

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I.C.I. 'Welvic' does the job best

'WELVIC' is backed by the finest research and technical service in the country. That service is available to all users and potential users of 'Welvic'. If you want advice on the uses of p.v.c. have a word with I.C.I.

'Welvic' extrusions manufactured by Duratube and Wire Ltd. are used for sealing expansion and contraction joints in concrete structures, plain and reinforced. The making of 'Dura-joints', as they are called, is but one of the very many applications of 'Welvic'.

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'Welvic' is the registered trade mark for the p.v.c. compounds manufactured by I.C.I.

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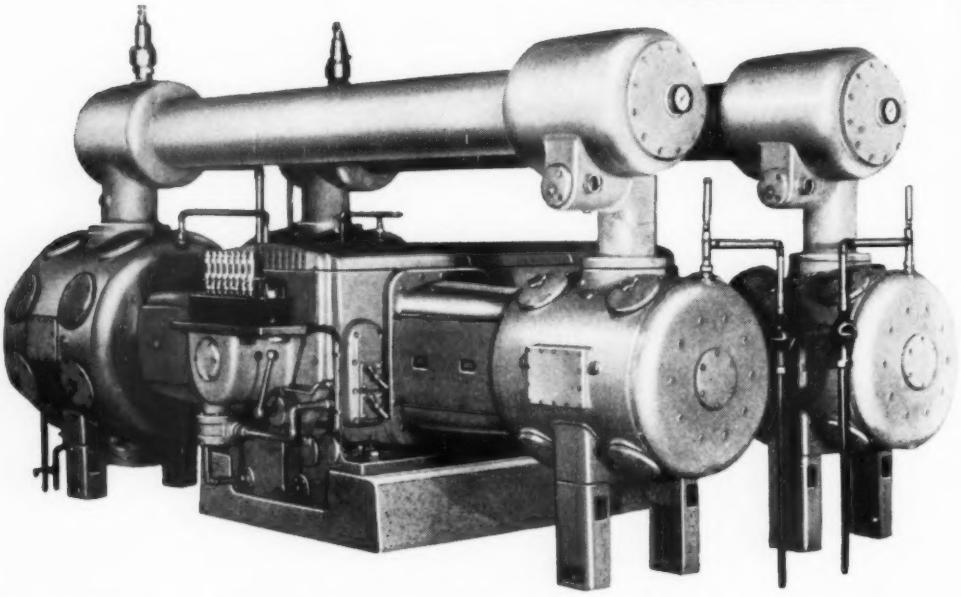
the standard **"FE"** compressor units can be assembled to suit your exact requirements for AIR AT LOWER COST

Class "FE" compressors are suitable for handling gasses other than air.



A Consolidated Pneumatic four-cylinder, four-crank, two-stage, double-acting horizontal balanced-opposed Class FE-42 Compressor. This unit requires 650 H.P. and delivers 3600 c.f.m. at 100 p.s.i. working pressure.

The advantage of standard Consolidated Pneumatic "FE" class compressor units is that they can be built up into single or multi-stage installations giving outputs up to 5,000 c.f.m. or pressures up to 3,000 p.s.i. to suit *exact individual* requirements, thus giving the most efficient return in terms of air delivered for power consumed. And, because the machines consist of standard units, the basic engineering cost of the plant as a whole is lower. Further, the virtues of the balanced-opposed design of these units are such as to effect considerable savings in foundation work, floor space and maintenance costs. In every way, "FE" compressors mean air at lower cost.

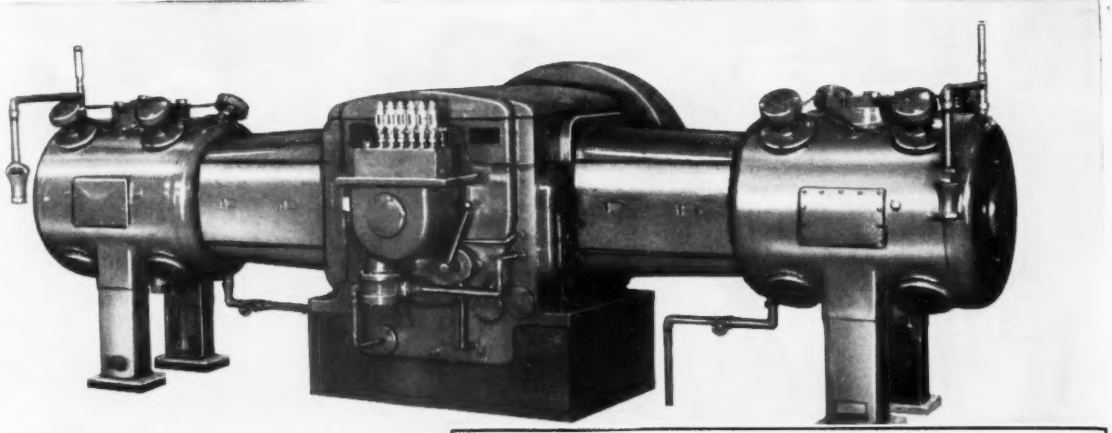
Consolidated Pneumatic CLASS **"FE"**

MAKERS OF AIR COMPRESSORS AND 480 DIFFERENT MODELS OF POWER TOOLS

CONSOLIDATED PNEUMATIC TOOL CO LTD · DAWES ROAD

*big-user class**

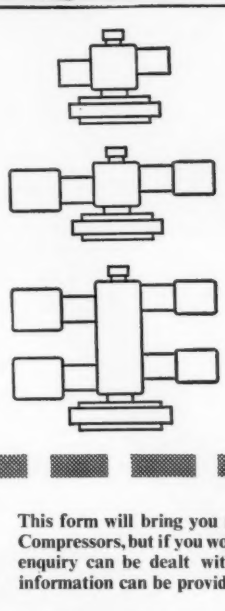
*** up to 5000 c.f.m. or 3000 p.s.i.**



A Consolidated Pneumatic two-cylinder, two-crank single-stage, double-acting, horizontal balanced-opposed Class FE-21 Compressor. This unit requires 250 H.P. and is designed for boosting natural gasses to a pressure of 75 p.s.i.

ADVANTAGES OF THE BALANCED-OPPOSED DESIGN

In the "FE" compressors, the crankcase and frame are centrally positioned with cylinders on opposing sides, the drive being obtained by a double-throw crankshaft. The resulting perfect dynamic balance makes for far greater compactness and virtual freedom from vibration, space and foundation work being reduced to a minimum. Also, the considerably smaller load imposed on main bearings, together with slow operating speed, ensure an extremely long life of continuous operation with very little maintenance.



1. The basic Class "FE" crankcase and running gear, showing also compactness achieved by using engine-type, salient-pole motor.
2. Different-size cylinders can be fitted, one-, two-, three- or four-stage machines being available.
3. Large outputs are obtained by increasing the number of cylinders and working off a common crankshaft.

For further information complete this form and pin it to your letter heading.

This form will bring you a descriptive catalogue on Class "FE" Compressors, but if you would like advice on a projected plant, your enquiry can be dealt with more expeditiously if the following information can be provided:

1. Output required in cubic feet per minute at intake pressure and temperature. _____
2. Intake temperature and humidity. _____
3. Intake pressure. _____
4. Discharge pressure. _____
5. Type of drive motor, voltage, etc. _____
6. Temperature of cooling water and type of cooling circuit. _____
7. Aftercooler, if required, and temperature of air at discharge from aftercooler. _____
8. Purpose for which compressor is to be used. _____

No. 35

COMPRESSORS

LONDON · SW6

CPI65

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accuracy and quality quickly 'take shape' in ...

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209

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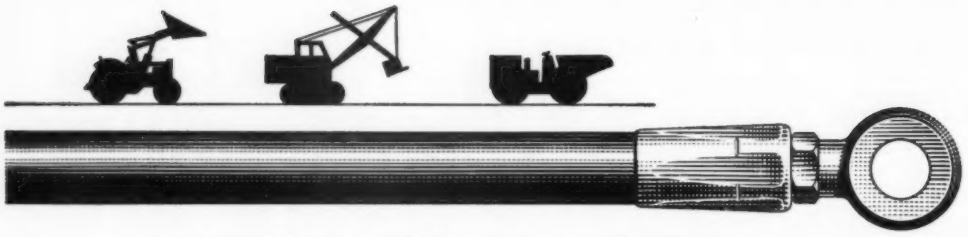
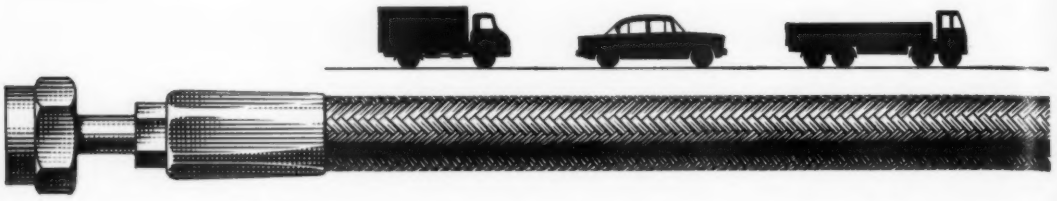


SWIFTLY AND EFFICIENTLY



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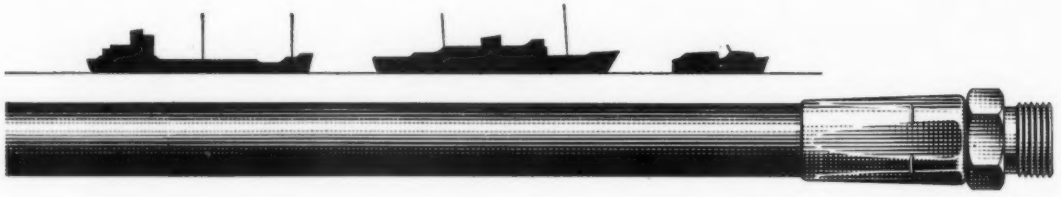

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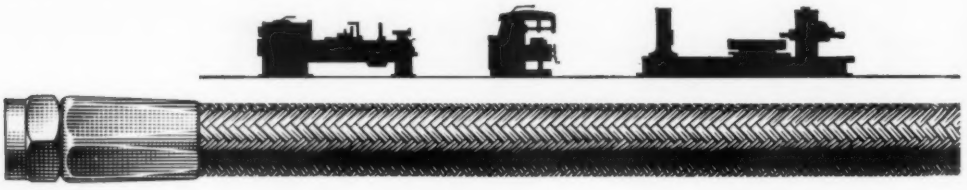

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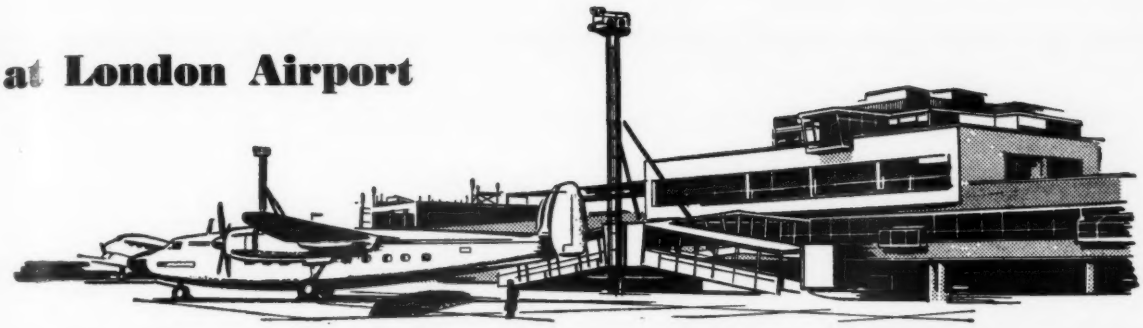

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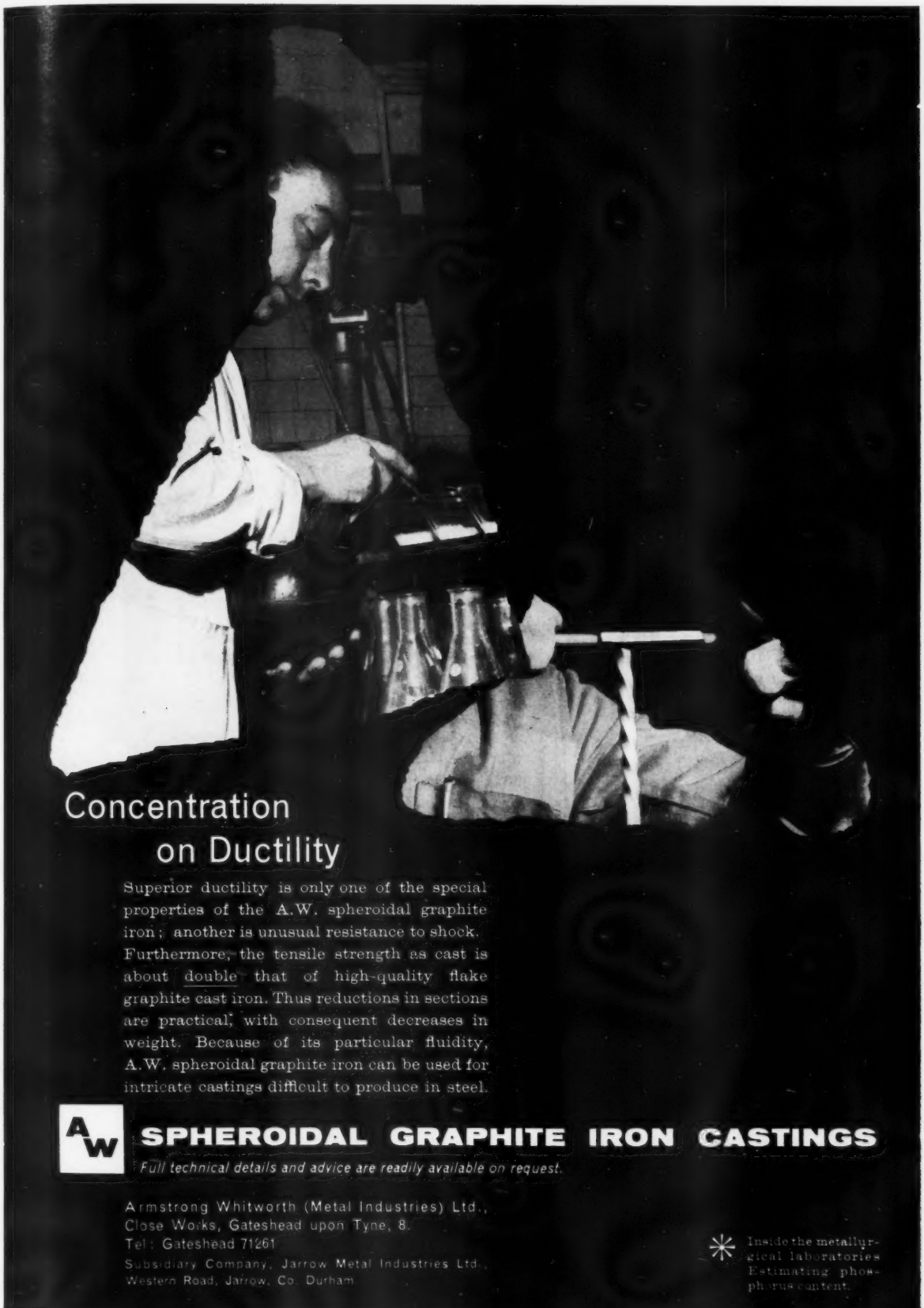

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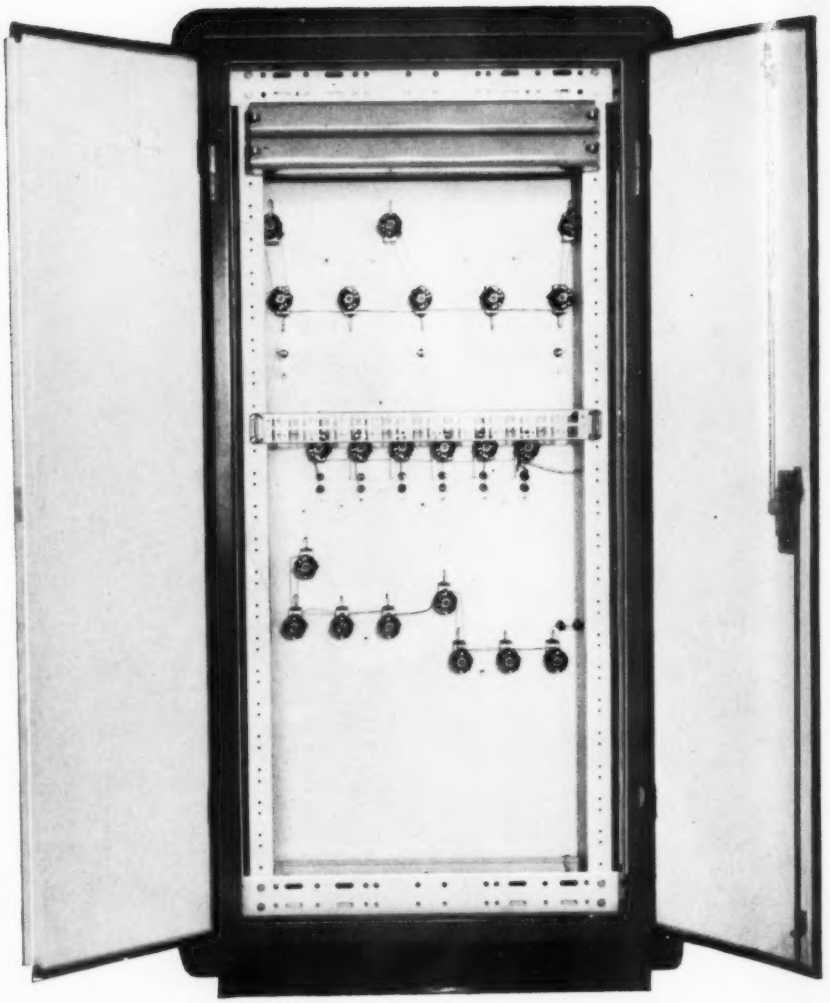

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Two versions—*one for controls, one for apparatus* **Two standard sizes** *for each version* **Rigid, all-steel construction**

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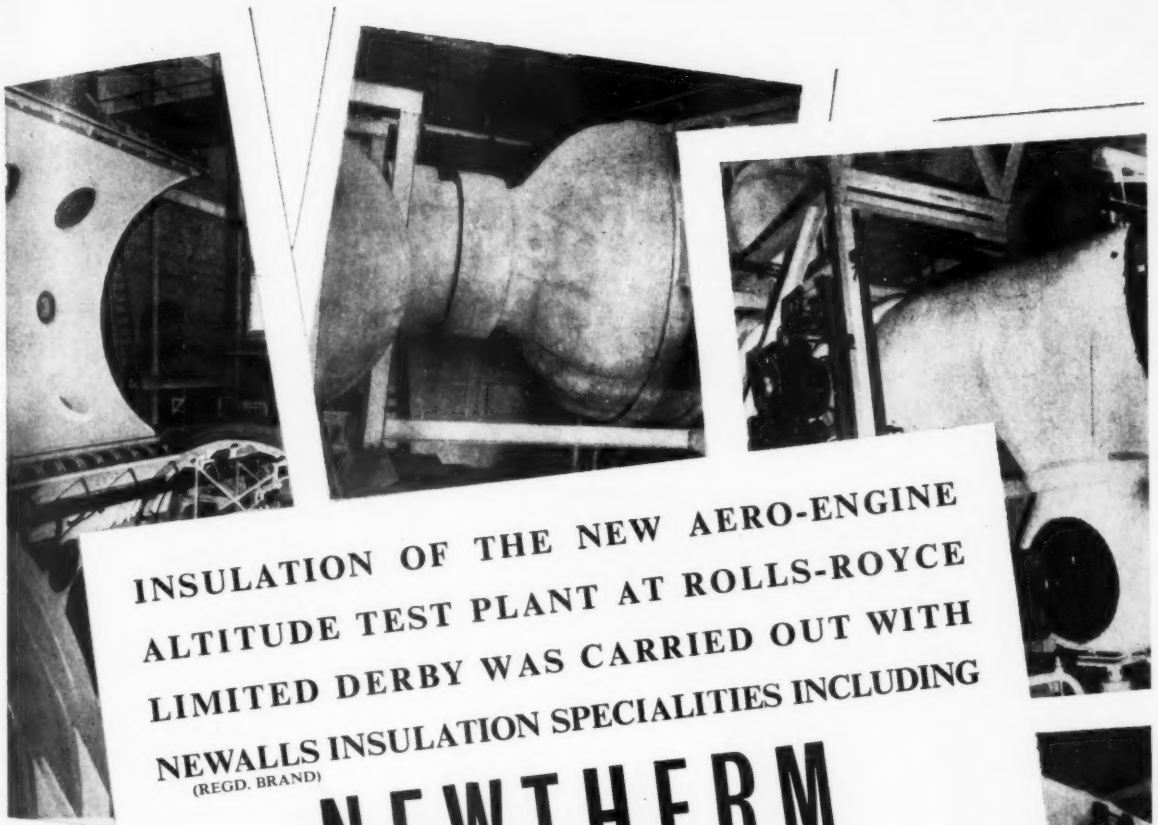

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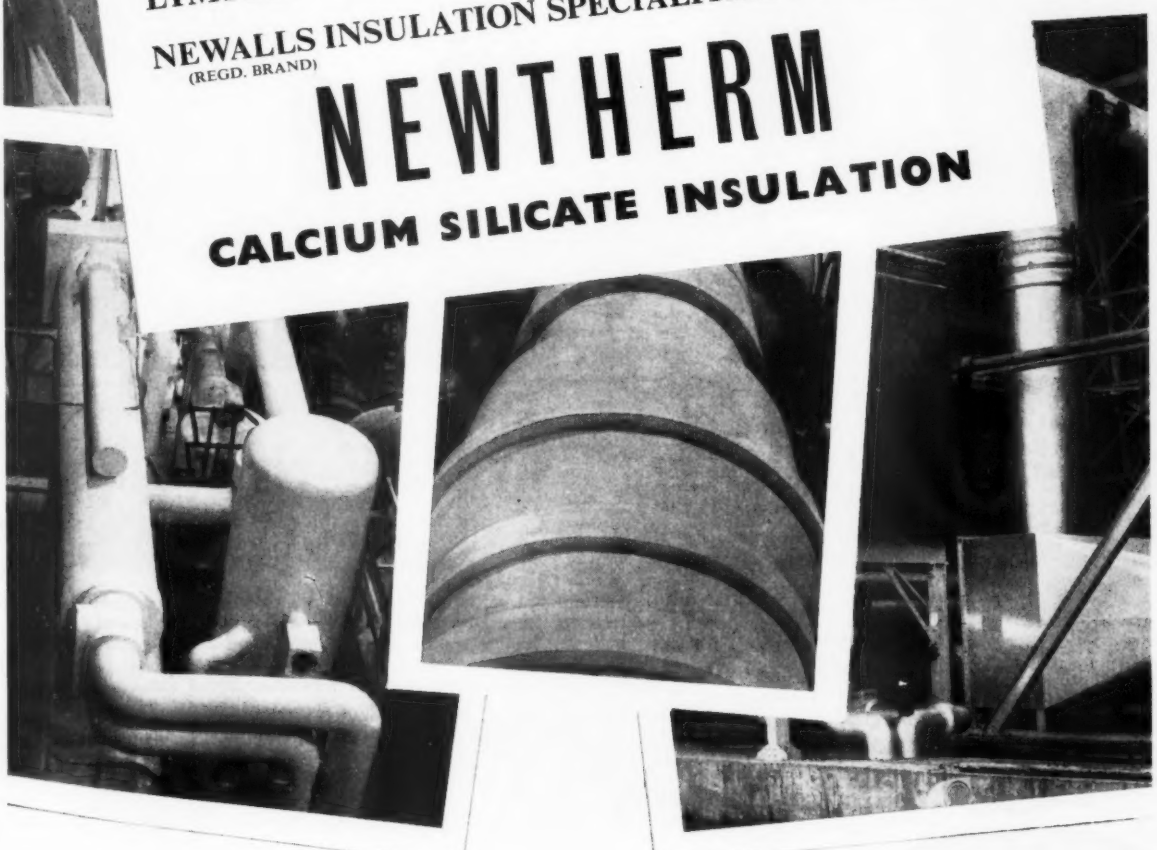

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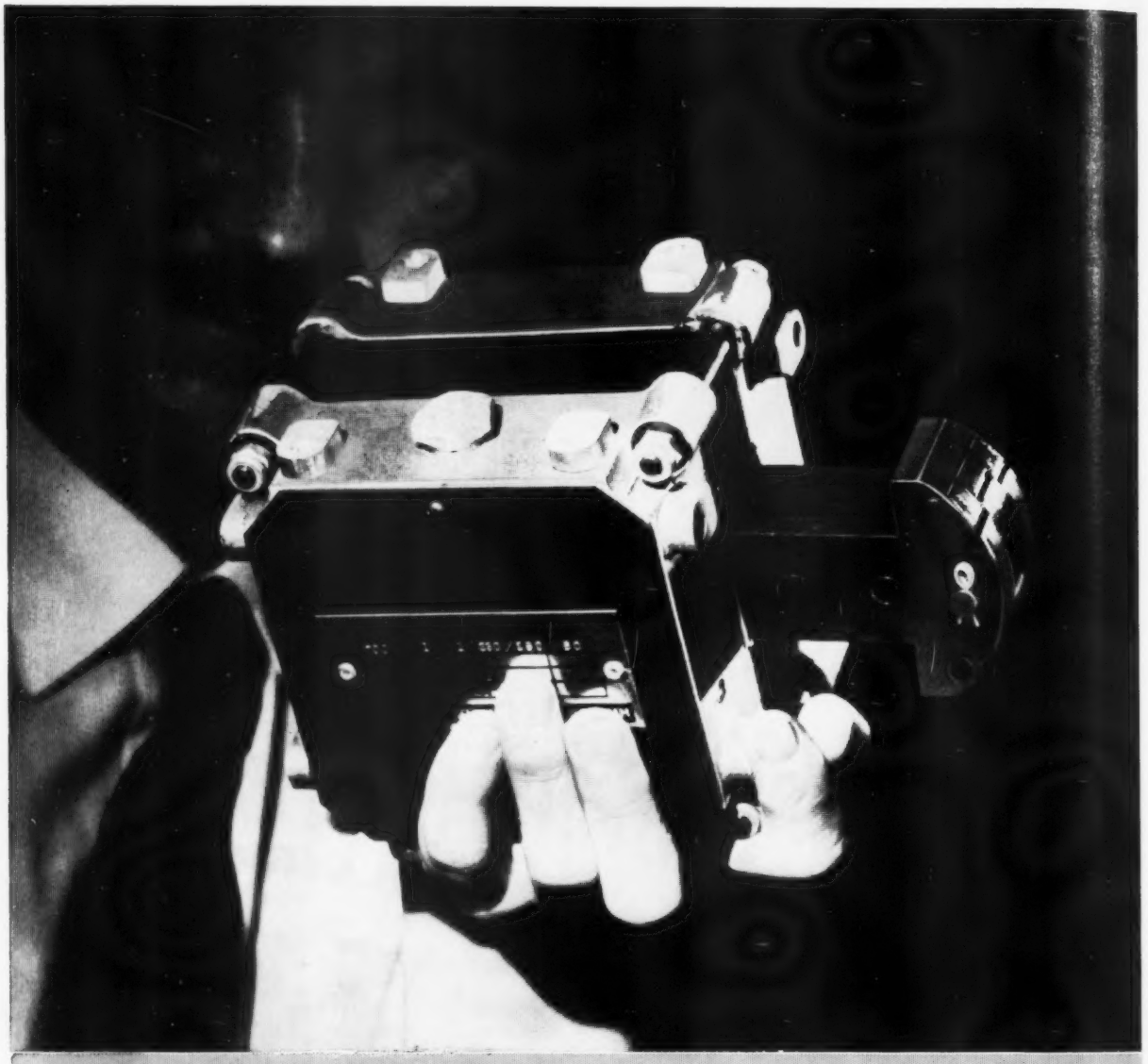
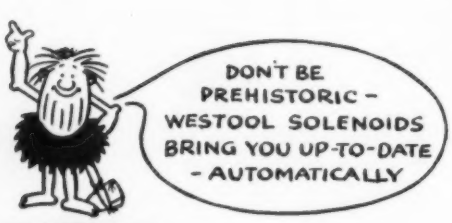


WESTOOL SOLENOIDS



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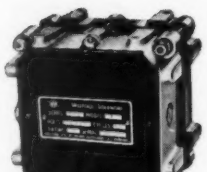
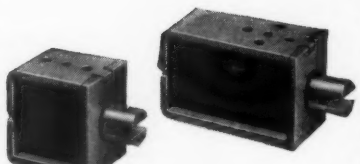
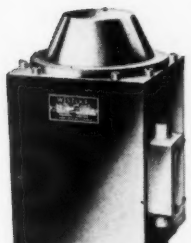


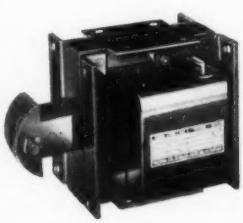
Series 700 A.C.



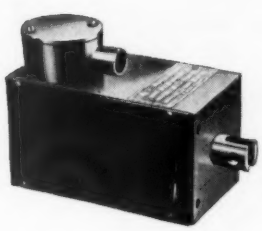
Miniature Solenoids A.C. & D.C. from 225 cm. grammes to 1.5 ozs.



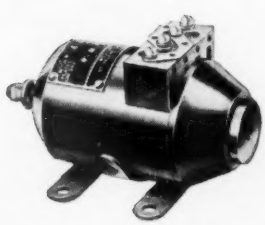
Series 'C', D.C.



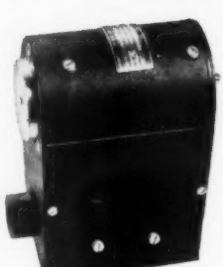
Series 600 A.C.



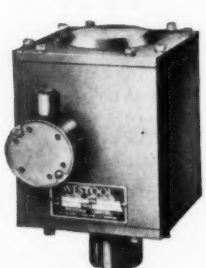
Series 'DK', D.C.



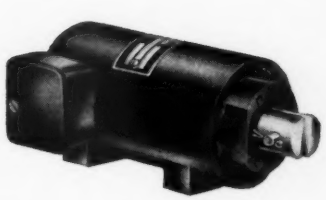
Series 1174 D.C.



Series 2030 D.C. with rectifier



Series 'E', D.C.



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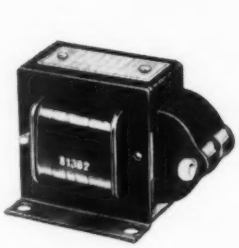
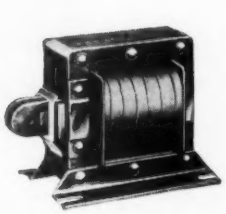
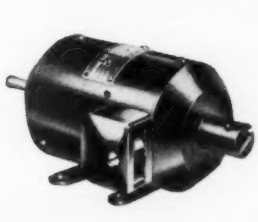


Series 500 A.C.



Series 400 A.C.



Series 2030 D.C.

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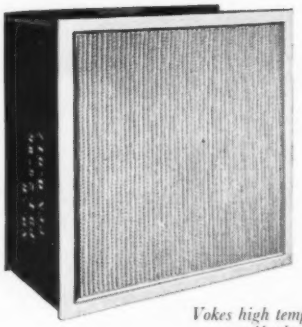
for high temperatures

(UP TO 1000° F)

Vokes high temperature 'Absolute' Filters

The complete safeguard

FOR APPLICATIONS where fireproof construction is required or where operating temperatures as high as 1000° F are prevalent, the high temperature 'Absolute' filter is the answer. Available in standard stock sizes as manufactured for the Atomic Energy Authorities and other users, this filter is also available with an all-glass paper filter medium with aluminium separators, but refractory sealers and metal frames are used in this case. The efficiency of this high temperature filter is exactly the same as that of the well-known standard 'Absolute' filter.



Vokes high temperature 'Absolute' filter.

The initial efficiency of 99.95% against a standard test cloud in the 0.1 to 0.5 micron range is guaranteed. Efficiency rises with use. Every Vokes 'Absolute' filter is fully and individually tested before despatch and is unreservedly guaranteed.
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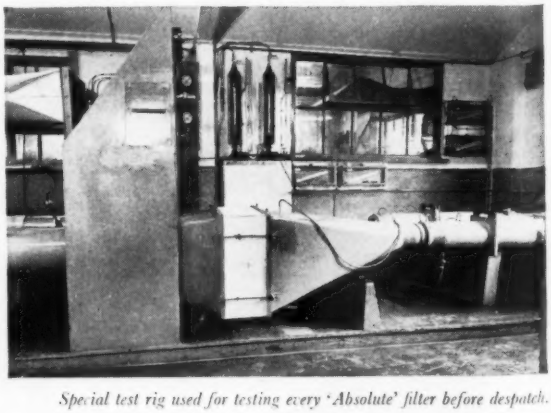

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V.320

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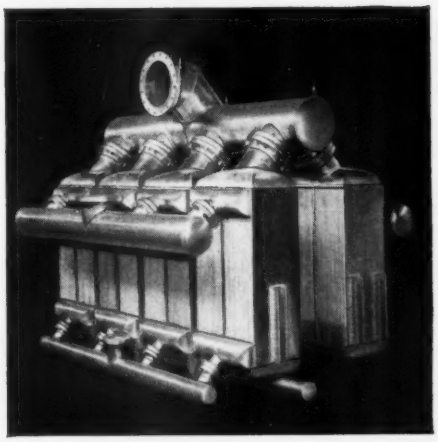

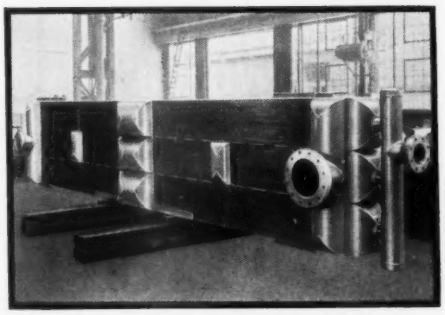

We have the biggest flux-dip brazing bath in Europe. It enables us to make the biggest secondary surface light alloy heat-exchangers this side of the Atlantic. But in heat-exchangers sheer size means little without comparable efficiency and reliability. They're the product of experience, and that is something we can also boast about. Marston brought flux-dip brazing to Britain in 1945. That means we've had longer experience of the process than any firm in Britain. It means we've had 14 years to perfect the technique of making the thousands of faultless joints in a secondary surface light alloy heat-exchanger. It also means we have unrivalled knowledge of design. Need we say more?

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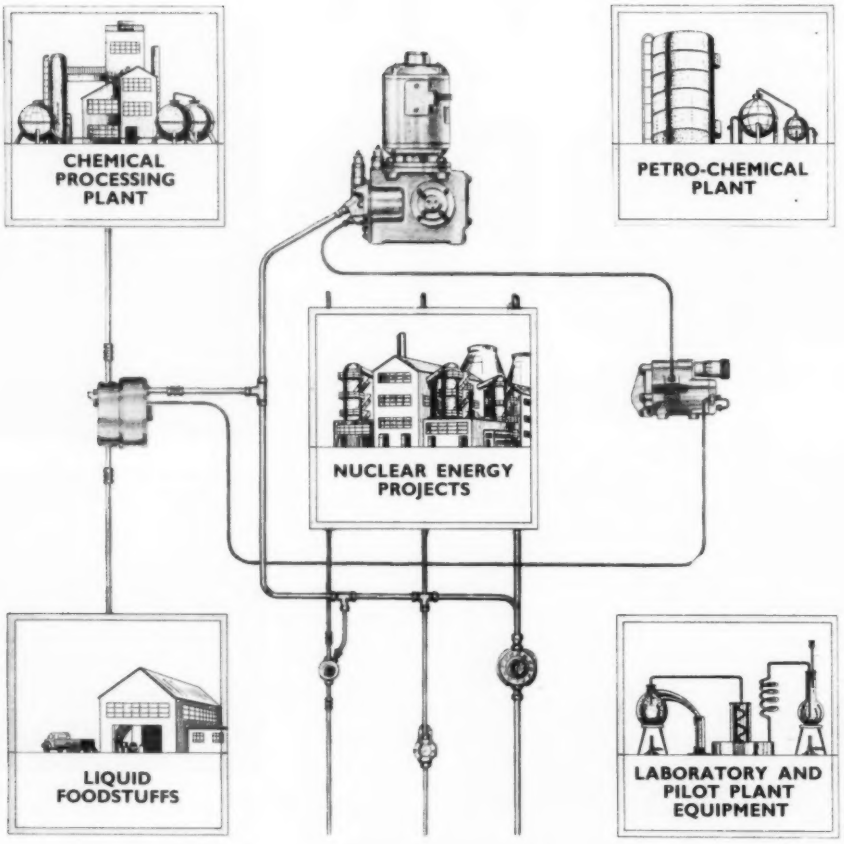
Accurate metering is assured by positive control of the diaphragm displacement.

The pumps are self-priming and any intentional or inadvertent stoppage introduced will not cause damage and correct metering will continue on release of the stoppage.



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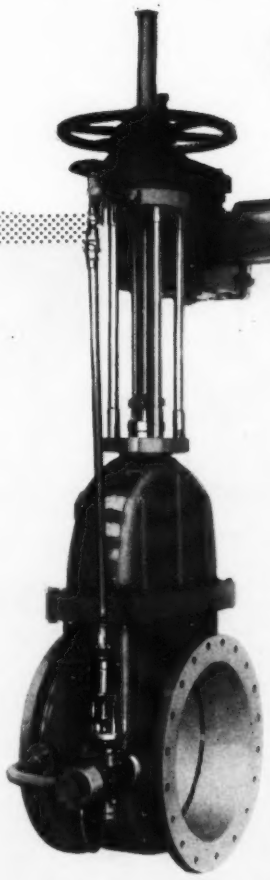

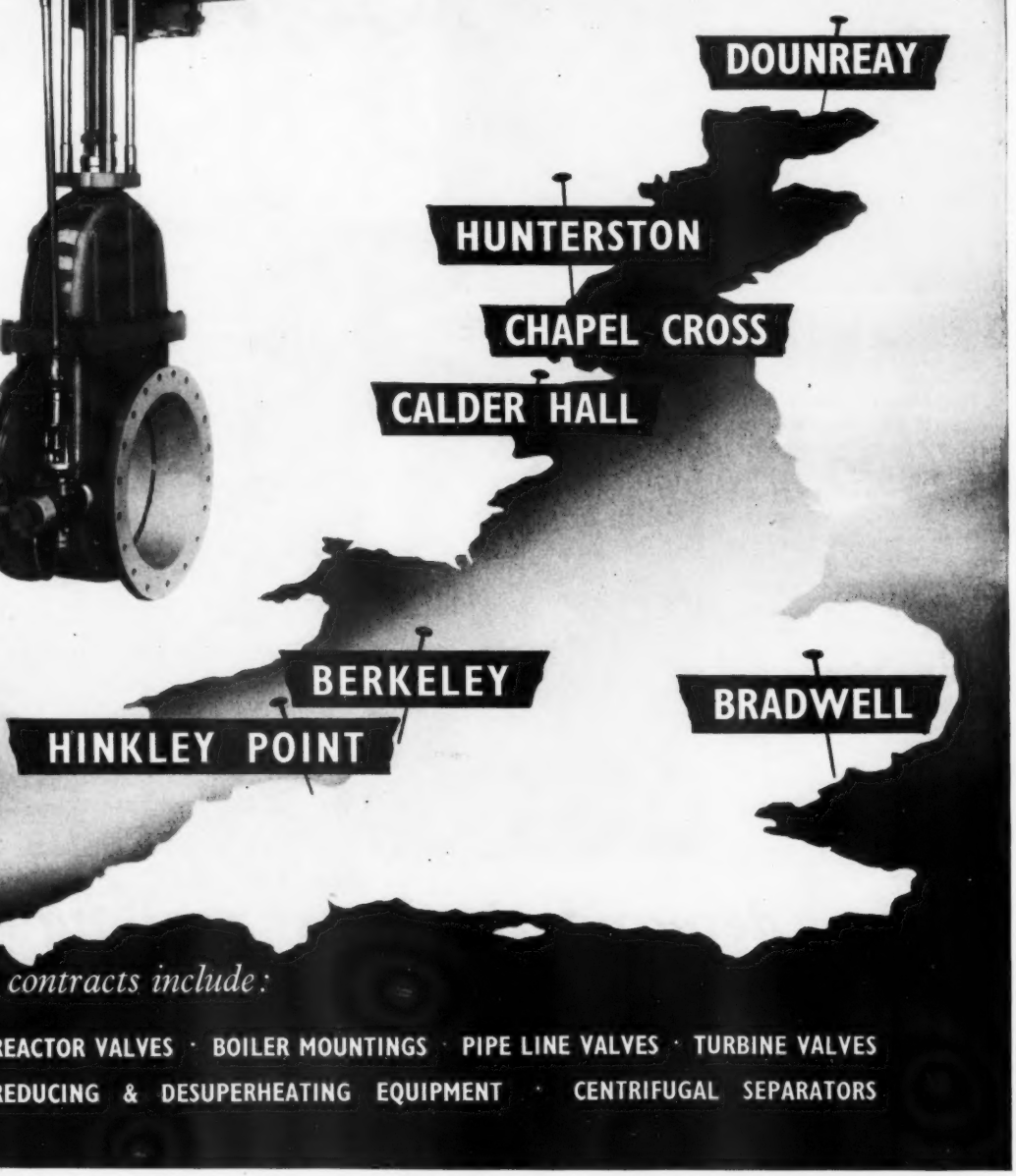

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HV109

most advanced Engineering Projects . . .

The growing demands and complexity of metallurgical analysis have made it increasingly necessary to supplement normal chemical methods by new physical aids. In the Quantometer, a controlled electric discharge vaporises a small amount of steel and excites the vapour so that radiations are given out characteristic of the elements present. The lower illustration shows the spectrograph (centre), the excitation units (right) and the measuring and recording console (left).

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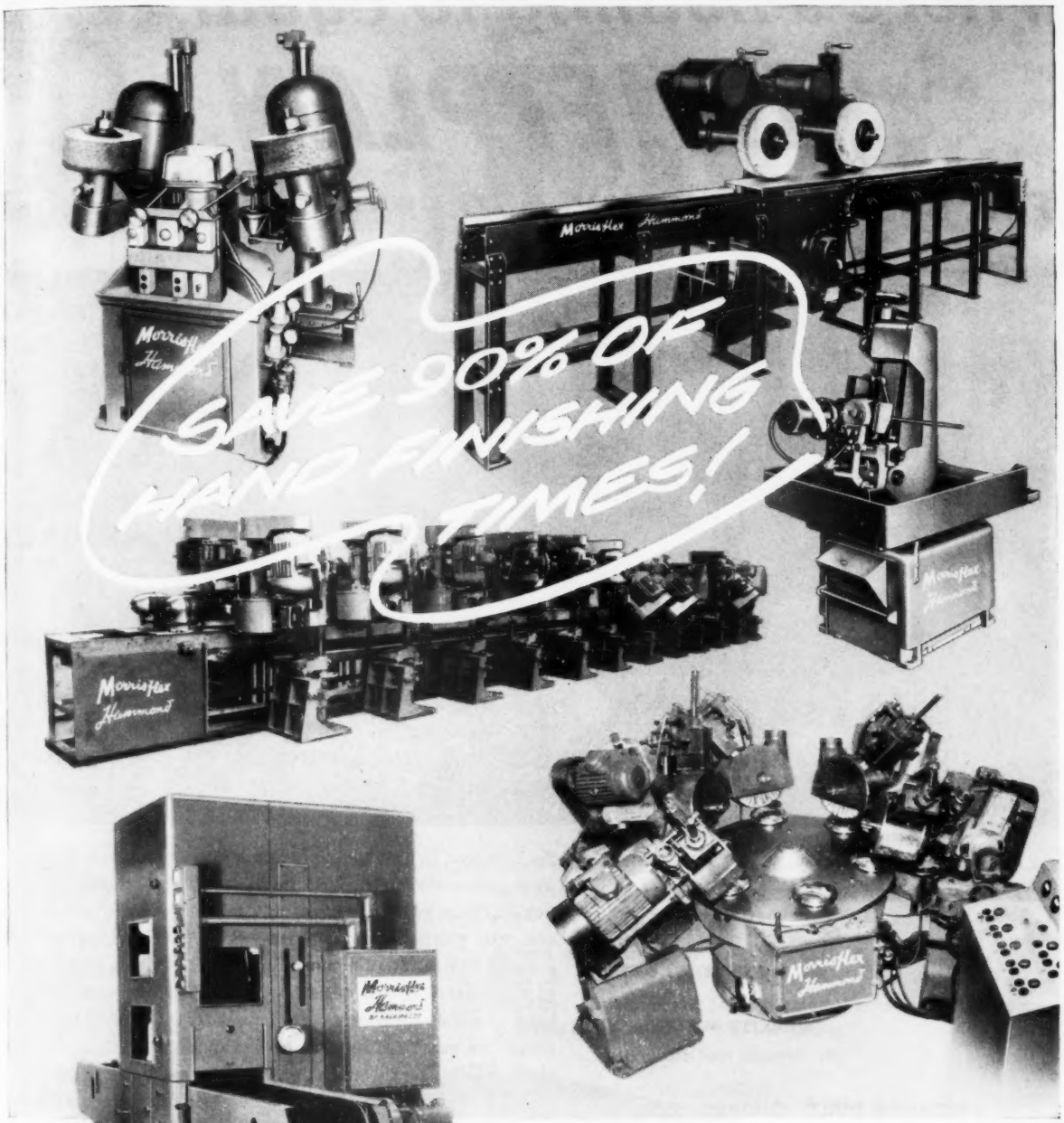

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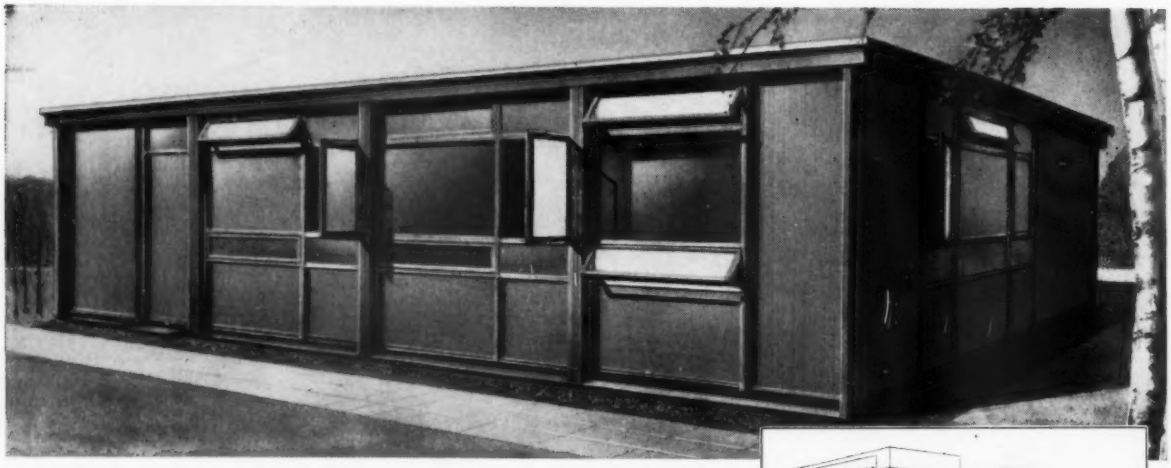

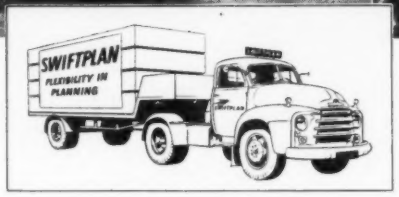

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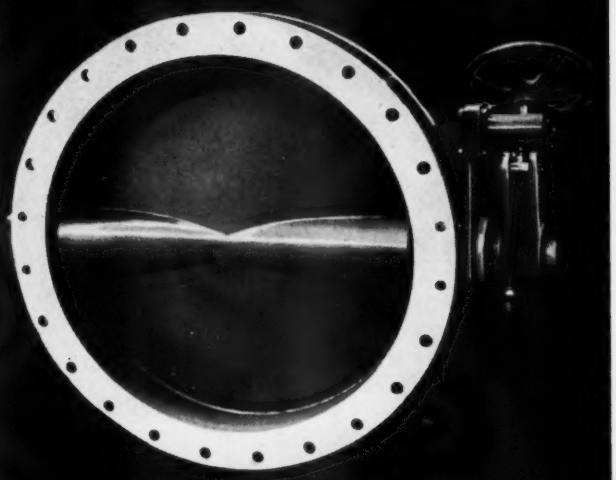
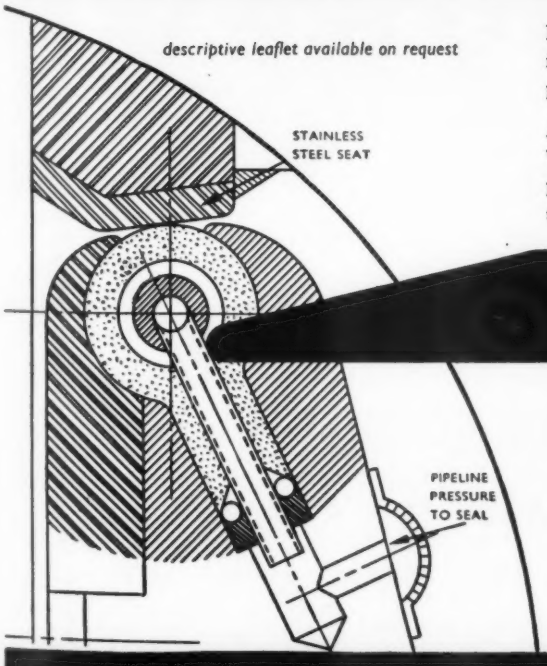
The reliability of this patented method of sealing has been proved in hydro-electric installations—after 25 years of service at heads up to 500 ft *the original seals were still intact.*



descriptive leaflet available on request



Low Pressure Butterfly Valves suitable for gases and fluids—including sea water. Vertical or horizontal mounting. Hand or power operated. Range 36 to 120 inches. Larger sizes to order.

Around the periphery of the valve blade is the expanding seal. With the valve closed the inside of the seal is subject to pipe-line pressure. This pressure balances external pressure and prevents seal from collapsing away from the seating.

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Pyrex beakers and flasks

are made in all practical sizes and shapes for students, routine or research work

Extremely low expansion coefficient

virtually eliminates breakage from thermal shock

allows more robust construction giving greatly increased mechanical strength

High stability

against attack from water and all acids (except hydrofluoric and glacial phosphoric)

THEREFORE durable, accurate, economical, dependable, most-used

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Some recent developments in manufacturing techniques and special applications of tubes in a variety of metals . . .

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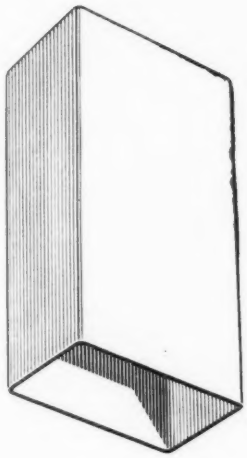
Annularly convoluted seamless stainless tubing, made in a range of diameters between ⅛"–2.715" o/d; suitable for flexible couplings, expansion joints, etc.



A rectangular wave guide tube in stainless steel, the dimensions are: .250" x .140" x .005/.007" thick. Close tolerances on dimensions, with smooth internal surface conditions, are essential.

Multibore tube in austenitic stainless steel with three bores .030" diameter, and solid nickel filler pieces. The outside diameter of the tube is .125".

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Makers and manipulators of COLD DRAWN SEAMLESS and WELDED PRECISION TUBES in carbon and alloy steels, including stainless steel, and other metals

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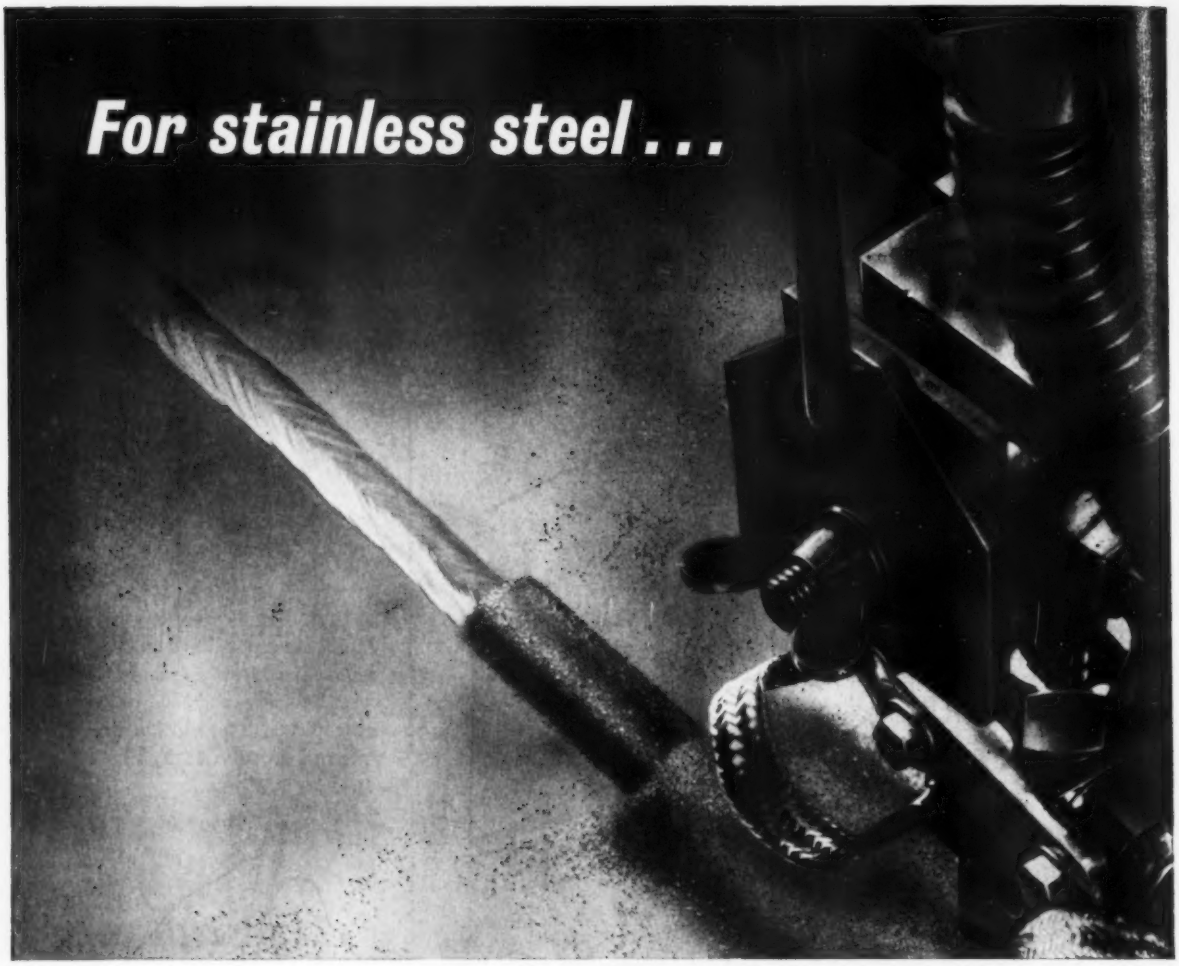

MUREX "MURAFLUX S.1"
stainless steel submerged-arc welding flux

The new "Muraflux S.1" granular flux has been specially developed for the automatic welding of stainless steel by the submerged-arc process. The flux is designed for the welding of 18/8 chromium-nickel steels and for use with Murex "Murawire S.W.1" or "Murawire S.W.2" filler wires.

This new Murex flux is suitable for either the single-pass or multi-pass submerged-arc welding of various joints in stainless steel in the flat position and welds of excellent appearance can be produced. A high radiographic standard can be obtained and the welds have good mechanical properties. High impact properties at low temperatures can also be obtained, an important feature in fabrications for sub-zero service.

When used with "Murawire S.W.2", the flux will produce a stabilised deposit and can therefore be used for applications of the 18/8 chromium-nickel steels such as fractionating columns, storage tanks, food vessels and pipe work where resistance to weld decay is essential.

Full details of Murex "Muraflux S.1" submerged-arc welding flux will be supplied on request.

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MUREX WELDING PROCESSES LIMITED, Waltham Cross, Herts.

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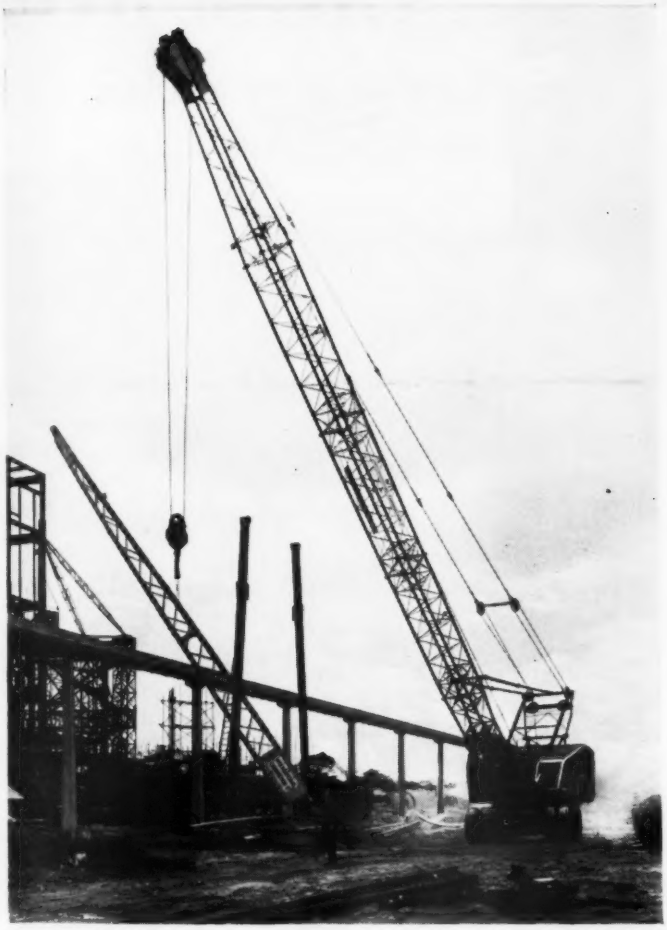
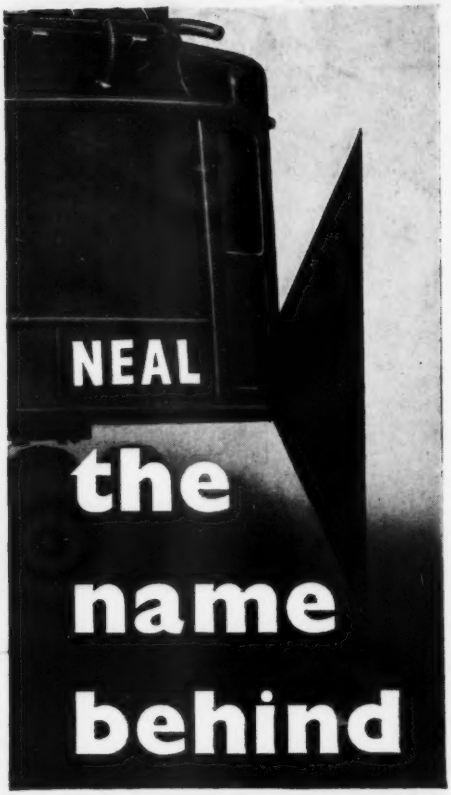


Type NS150 — 15 tons capacity

Photograph by courtesy of International Combustion Ltd.



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Type NS150	15 tons
Type NS70	6 tons
Type NS55	6 tons
Type NS45	4 tons
Type G.M.	15 cwts.
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"With their new TELEX service and speedy delivery fleet you can say Cashmore's stocks are my stocks—and that's why it's cheaper all round!"

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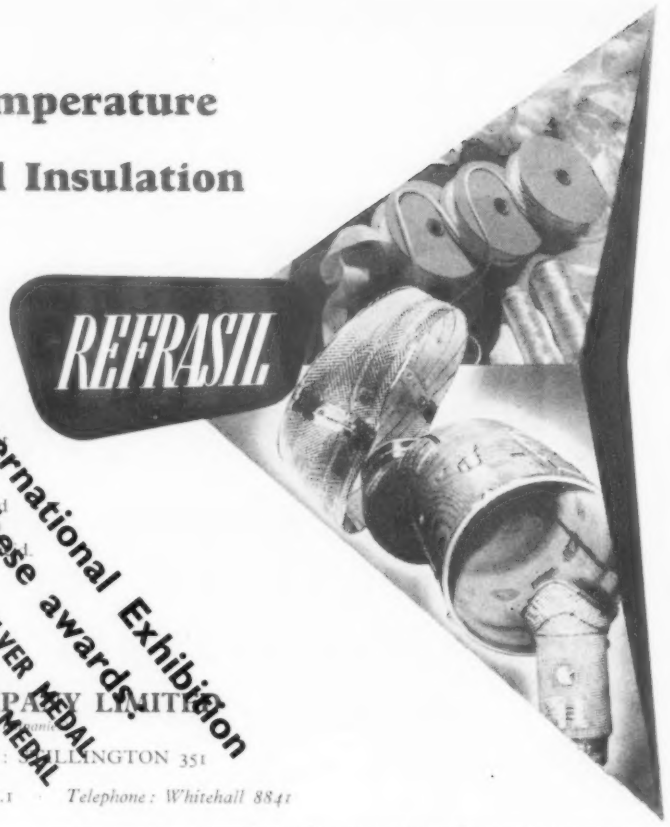

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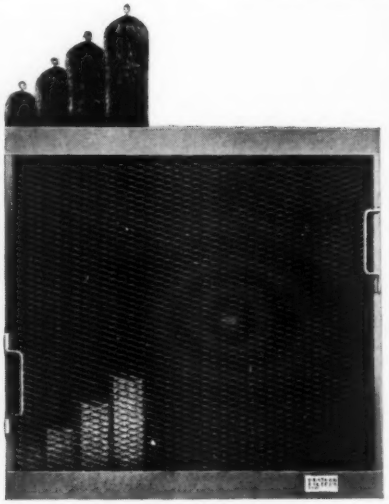
YOU CERTAINLY GET DUST-FREE AIR WITH THIS FILTER!



Present-day industrial conditions make efficient air filtration essential. To trap dust particles and impurities from the incoming air stream, Heather Multi-Brush Air Filters use a finely graded screen of intermingling hair specially selected to withstand varying humidity and other conditions.
This unique, low-cost filter system does not require special cleaning equipment, fluids, replacement pads or fabrics—simply remove the filter brushes and free them from dust by shaking or suction cleaning. Heather Multi-Brush Air Filters may be built-up into units to provide the area necessary for any given air flow.

** If you require a filter system that gives maximum efficiency with minimum maintenance, write* **NOW** *for leaflet H40 which gives full details.*

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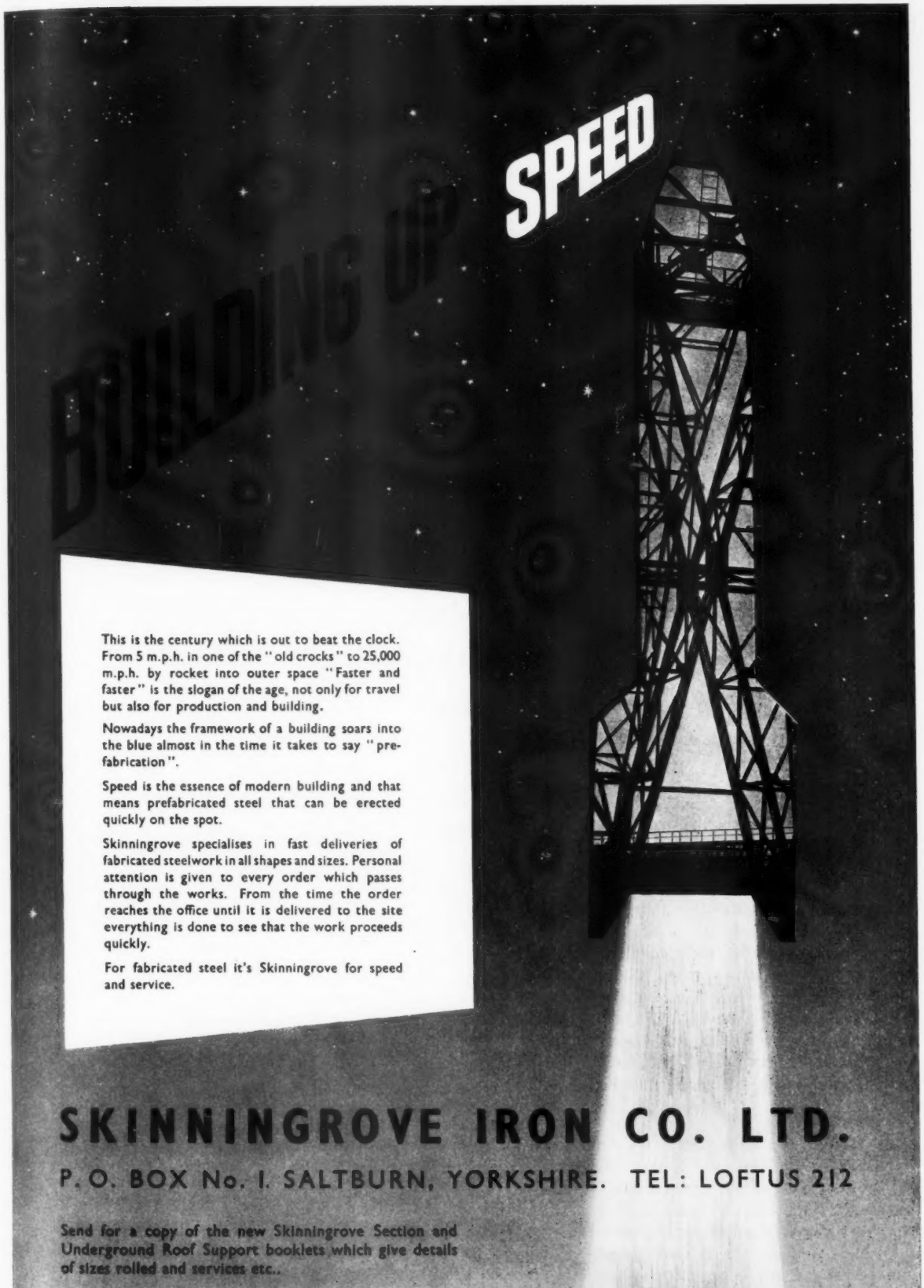
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Nuclear Power
REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · IRRADIATION

PUBLISHERS COLUMN

Year four

With this issue NUCLEAR POWER embarks on its fourth year of publication. Although not long for a technical magazine that's a fair distance at the rate nuclear energy developments move and to us, on the journal, our starting point seems a long way away now. What was happening in Britain in May 1956 when NUCLEAR POWER first appeared?

The first Geneva conference had been held the previous September and people were still digesting the mountain of paper there presented. Calder Hall was still under construction, although by now No 1 reactor was having its fuel loaded. On the commercial stations the Government White Paper has just been published. This announced a ten-year programme for the construction of between 1500 and 2000MW nuclear generating capacity and the first sites for stations had been chosen, although no contracts had yet been placed. The British Civil Estimates for 1956-7 showed a Government grant of about £M68 for atomic energy compared with £M106 for 1958-9. Thermonuclear was a mere word, although the second issue of NUCLEAR POWER carried a short account of Kurchatov's famous lecture at Harwell on April 25.

During these three years there have been several changes in the magazine and in fact it is still altering slightly month by month as we get closer and closer in touch with the real requirements of our readers. We suppose it always will. It has been a difficult but fascinating period and one which we don't think any of the staff would have missed—despite the occasional panic and long hours in the office or at the printers.

For the coming year—and future years, too, for that matter—our policy is perfectly straightforward: to continue publishing a lively, well-produced magazine of the maximum reader interest. If you have any constructive suggestions—or complaints!—send the Editor a letter. We assure you it will be most carefully considered.

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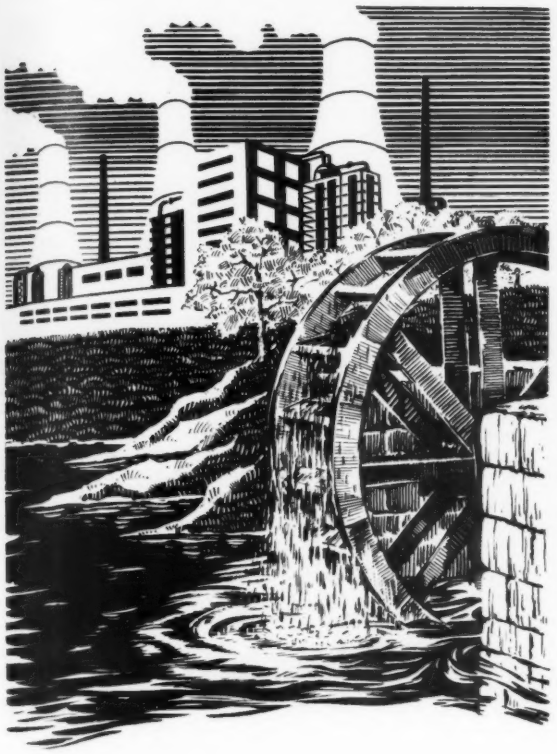

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SIR! LETTERS TO NUCLEAR POWER

The Editor welcomes correspondence for publication

Archetypal Bradwell ?

SIR: Has the graphite-moderated gas-cooled nuclear power station finally taken a definitive form as distinctive as that of a suburban semi-det or a bowler hat? When the first round of stations was announced, Bradwell and Hunterston were revealed as fairly similar in general appearance, with Berkeley looking markedly different. In the first two of these stations the essential function was largely concealed by the architecture but Berkeley seemed somehow more related to the purpose of the edifice. Since then we have had Hinkley Point, Latina (NPPC) and now the proposed Japanese station by GEC and it looks as if it was Bradwell which really set the general pattern of architecture, for all these follow very similar lines.

Hinkley Point is an interesting case of conformity. It will be recalled that the original English Electric design with architectural design by Frederick Gibberd was highly distinctive with considerable use made of semi-outdoor techniques. This was however rejected for technical reasons but when the successful design was finally announced it was revealed as following very closely the Bradwell pattern. Even in the AEI group conformity seems to be now strongly entrenched. So far this group have not obtained any contract beyond Berkeley but in their advertising (see e.g. NUCLEAR POWER *Jan* p 78) their latest ideas on the subject of architecture seem to be more or less identified with current trends. Atomic Power Constructions' ideas on appearance too, as revealed by their stand at Geneva, shows little original thinking.

Obviously one does not want stations that are merely idiosyncratic but can we be sure that this—after only two swift moves—is the ultimate design? Possibly it is, since the technical requirements force the the architects hands all the time but there is still a challenging architectural problem to be solved. Whether it ever will be or not will depend largely on the power station buyers.

London, W1 H. S. CLEAVER

The Belgian PWR

SIR: I was most interested to read Mr Gérard's account of his company's proposal for a pressurized water reactor in last month's NUCLEAR POWER (*'Belgium plans a PWR for Europe'*—page 86). I wonder however if he could perhaps amplify his cost figures. For example, it would be interesting to know what rate of burnup is guaranteed and how many fuel changes would be necessary during the station's 20-year life. Again, no credit is apparently taken for plutonium and this would presumably have some considerable bearing on the overall figure. Given however that Mr Gérard's 0·7 pence per kWh is realistic, and I have no evidence for casting doubts on it, the ACEC pressurized water reactor looks like a formidable contender for European contracts.

Liverpool P. L. JAMESON

▶ *We cannot speak for Mr Gérard but if you read his article carefully you will see that he answers at least one of your points. On page* 91 *he mentioned a core*

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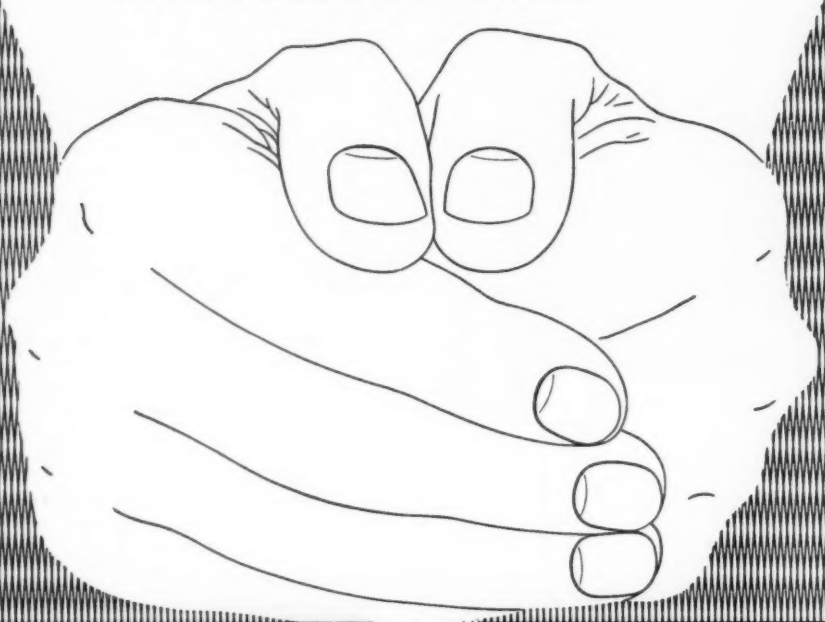

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SIR!

continued from p 75

lifetime of 10,000 hours at full power. Taking his 75% load factor this works out as about 6600 hours a year, giving refuellings at intervals of 18 months. *Ed.*

Potato clamps

SIR: In your article 'Fuel Elements Today and Tomorrow' the author refers to a German reactor (p 95) known as the 'potato heap' reactor. Have you any more information on this beyond that given in your magazine?

Smethwick K. HOOD

▶ *The reactor itself was described at Geneva by Dr R. Schulten of the German Brown Boveri Friedrich Krupp Nuclear Energy Group (paper 1054). The fuel element was covered also at Geneva by Dr Boettcher and colleagues of Degussa (paper 1005). As we announced in our March issue (Worldview p 83) a power experiment on these lines is now being projected as a prototype for larger plants. Briefly the reactor consists of a cylindrical vessel, funnel-shaped in its lower part. A critical mass of fuel balls is loaded into the vessel and heat is removed by circulating a helium-neon mixture (22:78) obtained by distillation of air. As fuel is burned up, the balls are removed from the bottom of the funnel and fresh ones added at the top. Fuel temperatures of up to about 1000°C are expected, with gas temperatures some 100°C below this. Dr Schulten believes that most of the primary circuit contamination will be caused by krypton and xenon and it is proposed to separate these from the coolant by adsorption on activated carbon at −190°C. Active graphite dust will be removed by filtration.* *Ed.*

Boiling in nuclear reactors

SIR: I wish to point out that the burnout heat flux quoted as 1,700 W/cm² on page 101 of the March 1959 issue is in error and should be 17,300 W/cm².

Oak Ridge National Laboratory W. R. GAMBILL

▶ *Mr H. A. Roberts writes: In Dr Gambill's paper the maximum burnout heat flux obtained was given as 54·8 × 10⁻⁶ Btu/ft²h as quoted in our article. We apologize for the error in converting to metric units; the true equivalent value should, of course be 17,300 W/cm² as pointed out by Dr Gambill.* *Ed.*

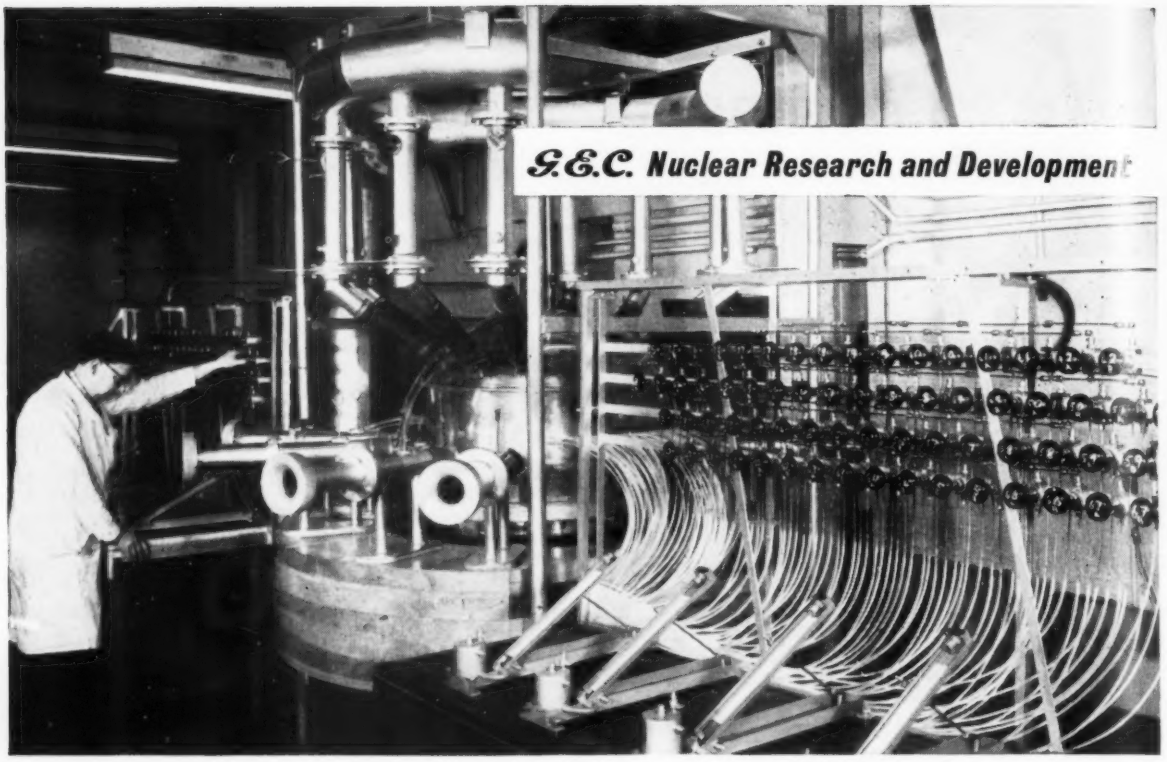
Bradwell progress

From the Publicity Manager, Nuclear Power Plant Co Ltd

SIR: We were very pleased to see two Bradwell progress photographs in the April issue of your journal (page 120). We notice, however, that you incorrectly captioned the interior view of no 2 reactor. Your title called it no 1 reactor and we think that perhaps this will give people a wrong impression of the amount of progress made at Bradwell.

Knutsford, Cheshire P. C. BRACEGIRDLE

▶ *We regret this error: it certainly did give an inaccurate impression. The picture was an agency one and the caption supplied was not specific on the point.* *Ed.*



Gas-flow model

In a gas-cooled reactor, there is an optimum value for the flow of coolant gas through each fuel channel to provide a given heat output. The flow must therefore be regulated, according to the power level, to achieve the maximum thermal efficiency of the system and to ensure that the operating temperature of the fuel elements is within the limits imposed by metallurgical and nuclear considerations.

There will be over 3000 vertical fuel channels in the 50 ft. diameter cylindrical core of each of the two reactors being built at Hunterston by G.E.C. A great deal of the theoretical and experimental work necessary to develop a design in which the total gas flow is correctly distributed over these channels has been done with the help of the gas-flow model shown above. This is a 1/20-scale model of a power reactor of the Hunterston type, and is installed in the laboratories of the G.E.C. Atomic Energy Division at Erith.

A 42-inch-diameter perspex sphere—which is a scale replica of the reactor pressure vessel complete with its supporting skirt, and rings of inlet and outlet gas-ports—houses a duralumin model of the reactor core. This core rests on a support-grid of the same "egg-box" type employed in the actual reactor. The channels for the fuel elements and control rods are represented by tubes whose number and diameter are such that the complete core offers a resistance to gas flow in proportion to the full-scale structures.

A motor-driven blower, coupled to the outlet ports in the sphere, draws air through the model to stimulate the flow of coolant gas in the reactor. Measurements are made of the air flow and the pressure drop along selected channels through the core using the pressure tubes and manometers on each side of the model.

Thus it is possible to investigate the symmetry of the gas flow through the reactor, and to study the effect of shutdown of one or more of the eight gas circuits connecting the pressure vessel to the steam-raising units. The influence of "gags", to restrict the flow of gas through the channels, can also be determined. This should save considerable time during the commissioning of the reactors.

G.E.C.

Atomic Energy Division

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Nuclear Power
REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · IRRADIATION
MAY 1959 VOLUME 4 NUMBER 37

Not so red

AFTER THIRTEEN YEARS, Britain's nuclear energy balance sheet is beginning to show something on the credit side. The Civil Estimates for 1959-60 for atomic energy—Government expenditure, in other words—show a reduction of about £M13·3 from £M106 to £M92·7 which is no doubt welcome news to the taxpayer. This does not however mean that less is being spent. The contrary; at £M124, the gross expenditure is greater than ever before.

The improvement in the net figures is due to the fact that during the current year the Atomic Energy Authority expects to make nearly £M24 from an item which appears in the Estimates merely as 'sales,' under the general heading of 'Appropriations in Aid.' The corresponding figure for 1958-9 was just under £M7, so increased sales are expected to amount to about £M17, by far the greatest contribution coming from the special nuclear materials of which the Authority has a monopoly under the 1954 Act—reactor-grade graphite and uranium. During this financial year graphite and fabricated fuel elements for the Central Electricity Generating Board's power stations will start stockpiling ready for loading into the reactors towards the end of 1960. Graphite sales will, it is understood, increase by about £M4 and fabricated elements by about £M10.

Another important revenue increase is in bulk electricity supplies from Calder Hall, which is now in full operation and from Chapelcross which will also become fully effective this year. This will amount to about £M3, which is quite a considerable sum for plants in which electricity has always been considered a by-product. Sales of isotopes for the financial year just ended are expected to amount to over £800,000; for 1959-60 they might well touch the million mark.

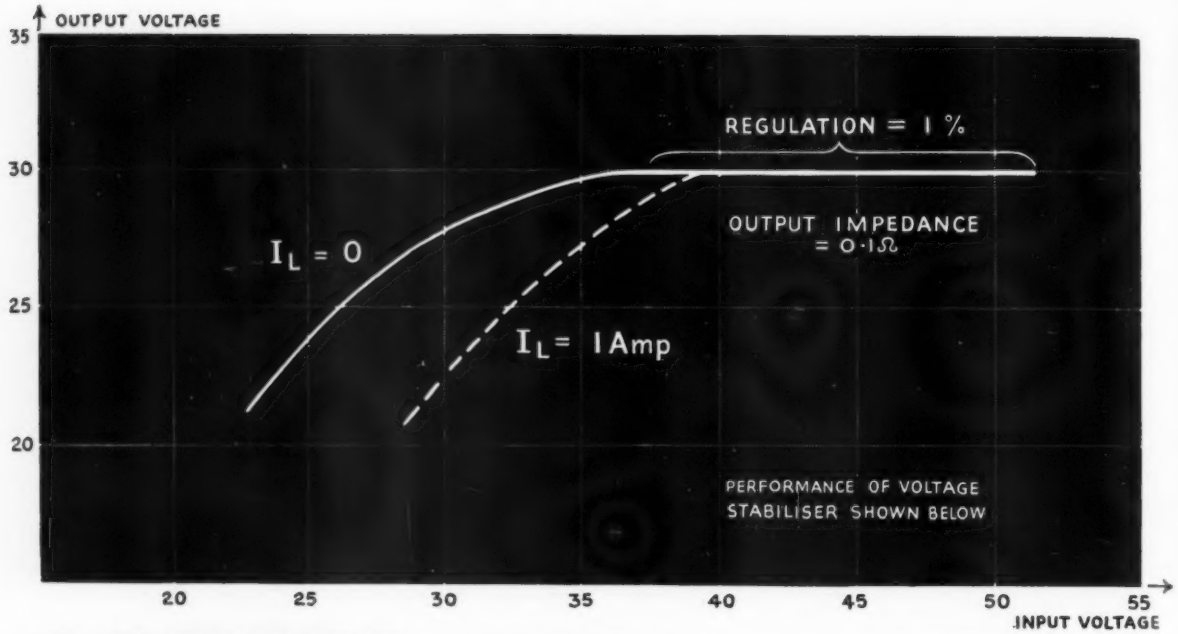
All this of course does not begin to lift the total operation out of the red but it is an encouraging tendency and although the Authority cannot hope to go on selling vast quantities of graphite, and natural uranium fuel elements indefinitely, the trade should certainly continue expanding for a few years at any rate. As it begins to taper off, presumably there will be things like enriched uranium, plutonium and thorium coming into the shop window.

On the debit side it is interesting to note firstly that whereas in 1958-9 uranium producers received loans totalling £M1, this year the amount has shrunk to a bare £10,000 which reflects the general view that supplies are now adequate to meet any foreseeable demand without the necessity for any more large scale mining development.

Money for the Authority's own establishments and projects shows little change in the total, although there are some internal readjustments, but this year the National Institute for Nuclear Research is to receive over £M4½ compared with £M2¾. Our contribution to CERN will be £1,225,000 but this appears under the DSIR vote.

On other international projects Britain is playing a substantial part. To the IAEA will go £190,000; to the Halden reactor project, £105,000 and to 'other reactor experiments in the UK,' £95,000. This is presumably the first instalment for the Winfrith Dragon project to which we are now committed to the tune of £M6 spread over the next five years.

As long as there is a military side to atomic energy the taxpayer will have a long bill to foot but it may not be unrealistic to hope that in time the purely civil area might begin to pay its way.



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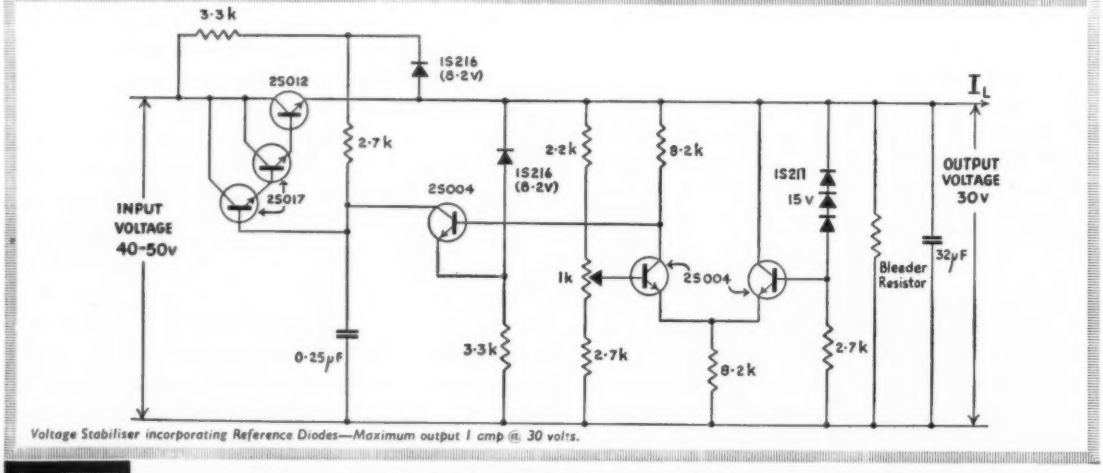
1S207	3·6	20	22	0·15	20	400	80	−0·055
1S214	6·8	20	5	0·1	20	400	80	+0·035
1S218	10·0	20	12	0·1	20	400	80	+0·060



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Worldview

the month in atomic energy

IAEA to have own facilities

During the series of meetings which commenced on April 7, the Board of Governors of IAEA approved the plans for the setting up of a functional laboratory. This installation will be used for work on the standardization of isotopes and the preparation of radioactive standards; quality control of special materials for nuclear technology; measurements and analysis in connexion with the Agency's safeguards and health programme and services for Member States. The US is contributing $600,000 towards the cost of construction and the Netherlands are presenting a Gamma-Spectrome.

The laboratory will be built on a site adjoining the Austrian atomic establishment at Seibersdorf, near Vienna. It will closely cooperate with, but will not duplicate, the reactor and laboratories of the Austrian unit and will use the same chemical and low activity waste disposal system. IAEA's laboratory is scheduled to be in operation from the first quarter of 1961.

Draft agreements approved

The IAEA has approved draft agreements between the Agency and the USSR, the UK and the USA for the supply by these countries of nuclear materials to the Agency. The offers were originally made at IAEA's first General Conference and the present draft agreements incorporate the basic terms and conditions.

The USSR has offered 50 kg of uranium-235, with any enrichment up to 20%, in either metallic form, chemical compounds or as fabricated fuel elements. The prices will be based on a scale of charges corresponding to the lowest international prices in force at the time of delivery.

The British offer covers 20 kg of uranium-235 and may be supplied in any concentration up to 20% enrichment and there is also provision to higher enrichment for specific research purposes. The price and conditions are such that they will not be less favourable than any of those offered by the UKAEA to other external customers.

The USA will supply 5000 kg of contained uranium-235 together with such additional quantities of nuclear materials as will match in amount the total of all supplies of these materials by other members of the Agency prior to July 1, 1960. Charges applicable to domestic distribution will be made by the American AEC. In addition, supplies will be made available without charge for research on peaceful uses or for medical therapy up to a quantity not exceeding $50,000 in value per annum. The materials covered by all three draft agreements will be retained by the supplying countries until needed by the Agency.

Planning for safety

With the increasing use of radioactive materials all over the world, the need for the adoption of safe transportation has become particularly urgent. A panel of experts convened by IAEA met in Vienna early in April to discuss the problems associated with the safe transportation of isotopes, ores and low specific residues of active materials. In the course of the next few months, another panel will be convened to cover highly radioactive materials such as irradiated fuel elements and concentrated wastes. The aim of these panels is to formulate safety regulations which can be uniformly applied by Member States and other organisations concerned with air, water and land transportation. It is desirable that the essential requirements are uniform for the three forms of transportation and complicated procedures do not have to be followed by shippers and carriers.

Requests for help

Following the visits of IAEA missions in recent months, the Agency is now considering the best means of aiding Burma, Ceylon, Greece, Indonesia, Thailand and the United Arab Republic. Already requests from Burma and Greece have been received for equipment and experts and these are under current consideration by the IAEA.

First fuel deal

On March 24 the first nuclear fuel transaction arranged by the IAEA was successfully concluded in Vienna. Two agreements covered the supply of uranium from Canada to the Agency and the supply to Japan. The agreements were signed by the IAEA Director General, Mr Sterling Cole and by Mr W. H. Barton and Ambassador H. Furuuchi, on behalf of the Governments of Canada and Japan respectively. The supply of materials to Member Countries is one of the most important tasks of the Agency and the Chairman of the Agency's Board of Governors expressed the hope that other requests for supply and offers of material would be made. The agreement between IAEA and Canada includes the specifications covering the natural uranium, the size of the billets, density, surface conditions and chemical purity. Delivery is to be completed within three months. The contract between the Agency and Japan incorporates the Agency's handling charges and specifies the safeguards that are to be initially applied, pending the adoption by the Agency of general safeguard and inspection procedures.

Further visits

To achieve closer cooperation between Member States and the IAEA, Mr Sterling Cole, the Director General, accompanied by Mr Johan Halberstadt of the Department of Research & Isotopes and Mr Witold Lisowski of the Department of Training and Technical Infor-

HUNGARY'S FIRST REACTOR went critical on March 25. This 2 MW Soviet-type WWR-Z unit is located at Czilleberg, near Budapest

mation, visited Bulgaria, Hungary and Rumania between March 28 and April 4. In the second half of April, Mr Sterling Cole visited Greece, Israel and Turkey.

UK scientist in Greece

The first Visiting Professorship to be arranged by IAEA will be held by Dr A. G. Maddock of Cambridge University. He went to Athens on March 27 and is giving a month's series of lectures at the Greek Atomic Energy Commission's (GAEC) radioisotope training centre. Dr Maddock will also advise the GAEC on the operation of a provisional radiochemistry laboratory now under construction and on plans for a permanent laboratory that the Commission intends to build. This will enable experience to be gained prior to a nuclear power plant being built.

EURATOM

Joint programme starts

Under the terms of the US-Euratom cooperation agreement signed earlier this year, proposals have been invited from industry for the installation of nuclear power plants having a total capacity of 1000 MW. The reactors chosen will be US types but may be wholly or partly manufactured in Europe. Participants are to submit their proposals before September 1, 1959, when they will be jointly reviewed by the American AEC and Euratom; the selection of suitable projects will be made prior to December 31, 1959. The agreement affords special advantages by way of loans and financial guarantees for these projects and it is planned that the construction work should begin in April, 1960. The final date for the completion of the power installations is set at December 31, 1963; but two of the projects may be prolonged for a maximum of two years in order to profit from future technical developments.

CANADA

New reactor idea

The Canadian General Electric Co are working on a totally new reactor concept involving heavy water moderation with organic cooling. Known as OCDR (Organic Cooled Deuterium Reactor) it is thought to promise lower capital costs than the heavy water reactors but rather higher fuel costs. This was disclosed by the Vice-president of Atomic Energy of Canada, W. B. Lewis, giving the James Clayton Lecture to the Institution of Mechanical Engineers in London on April 10. Mr Lewis said that as part of the design study an organic loop was now working in the NRX reactor at Chalk River.

Talking generally about Canada's progress since 1951, Lewis said he had to admit it was slow but attributed this to 'the circumstances of abundant power in which we live.' Conventional power costs, he considered would still remain low even when water power is completely utilized and this woud set Canada a challenging problem. Scientific and technical problems of atomic energy had, however, now been reduced to manageable proportions and brought into the realm of engineering and estimates. 'Others' concluded Mr Lewis 'may be able to take advantage of our development and we hope we shall not find ourselves standing alone much longer in this low cost competition.'

Design for fuel testing

A low-power reactor, known as ZED-2, designed specifically for testing the fuel arrangements in large power reactors is to be built at Chalk River. It is similar in design to the ZEEP reactor which went into operation in 1945 but will be larger to permit more extensive fuel rod experiments than could be carried out in the earlier reactor. It is expected that this new reactor will be ready to go into operation early next year.

FRANCE

Potentialities reviewed

The Commissariat à l'Energie atomique will present a summary of its activities and the potential uses of nuclear energy in France at the Electrama Exposition to be held in Paris from June 12 to 18, 1959. The Commission will demonstrate its more recent achievements in the industrial and technical fields of nuclear engineering. For the first time, a French swimming pool reactor, fuelled with enriched uranium, will be shown to the public.

HUNGARY

Criticality achieved

The first Hungarian experimental and research reactor located at Czilleberg on the outskirts of Budapest went critical on March 25. This 2 MW reactor is of the Soviet light water-moderated and -cooled WWR-Z type and uses 10% enriched uranium oxide. Assistance in the construction of this unit was provided by the USSR.

ITALY

Building at Casaccia

The CNRN has recently awarded the contract for the building of the first section of the Nuclear Study Centre of Casaccia, some 12 miles north of Rome. This work will cover the housing of the Triga II reactor, which is expected to become critical by the end of the summer; the gamma field for plant mutation research; and part of the Biology Laboratory.

First centre opened

On April 13, President Gronchi formally opened the Ispra centre for nuclear studies. This is Italy's first atomic centre at which she will be able to carry out her own applied research. Sir John Cockcroft, Director of the AERE and Mr John Floberg of the American AEC attended the ceremony and the Italian President was presented with a cheque for $350,000 from the US Government as a contribution to the research programme.

Legal security lacking

That the lack of a sound legal basis presents an obstacle to future developments was expressed at the meeting of the 'Committee for the Problems arising

LATINA—ITALY'S FIRST NUCLEAR POWER PROJECT. An artist's impression of the 200 MW graphite-moderated, CO_2-cooled reactor powered generating plant, at present under construction, 40 miles south of Rome, by the Nuclear Power Plant Co. Completion is scheduled for mid-1962

from the Peaceful Uses of Nuclear Energy and for Relations with Euratom' held on March 12 at the headquarters of the General Confederation of Italian Industry.

The committee recommended that private and public enterprises should have equality in carrying out their programmes, the law should encourage development and it should be consistent with the Euratom Treaty.

JAPAN

Power plant deals

On April 3 the Japan Atomic Power Co issued a letter of intent to The General Electric Co Ltd for the construction of the 150 MW nuclear power plant at Tokai Mura, some 70 miles north-east of Tokyo. This order, worth approximately £M20, results from protracted negotiations which have been extended over many months and it is anticipated

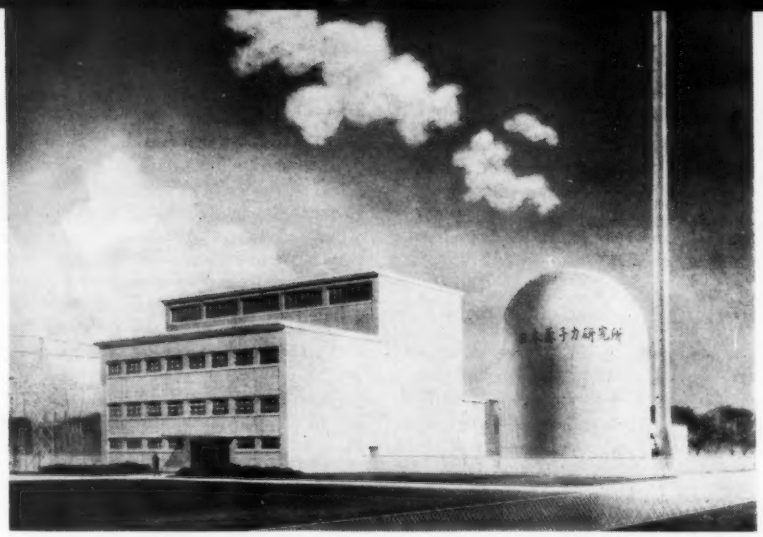
AEA EXPORTS. Mr. Ipponmatsu of the Japan Atomic Power Co and Lord Plowden for AEA sign agreement

that it will be some time before the project has been examined and approved by the Japanese, enabling the final contract to be concluded.

Early in April Mr T. Ipponmatsu, Vice-chairman of the Japan Atomic Power Co, visited England to continue the discussions with the GEC, took the opportunity of touring the Hunterston site and the AEA's Springfields factory. He also had discussions with AEA and an agreement was reached giving Japan technical assistance in her development programme. A letter of intent was given to Mr Ipponmatsu by AEA covering the supply of fuel for this power station project.

BWR too

The Japan Atomic Energy Research Institute (JAERI) have placed a contract with the International General Electric Co for a 12½ MW boiling water reactor. It will be used for research and development as well as power production and will be located at JAERI site at Tokai



12½ MW BOILING WATER REACTOR FOR JAPAN. Expected to be the first nuclear power plant operating in the Far East, IGE will build this unit at Tokai Mura

Mura. The plant will be built by GE in America and the Nippon Atomic Industries Group, as sub-contractors, will supply certain components and services. The reactor is expected to go critical late in 1961, in which case it will be the first nuclear power plant to go into operation in the Far East. This is the fourth power reactor to be built by the IGE.

Germany takes a look

Herr Siegfried Balcke, the West German Minister for Atomic Development, made a twelve-day visit to Japan at the end of March. As well as meeting leading Japanese industrialists he made a close study of Japan's progress in nuclear marine propulsion development.

NETHERLANDS

Looking to the sea

During the Technical Trade Fair which is being held at Utrecht from April 15 to 24, a one-day conference is being devoted to the use of nuclear power for ship propulsion. Mr H. W. Bowker, leader of the Marine Propulsion Group at the AERE, Harwell, is among the experts addressing the meeting. This session is being attended by shipbuilders and owners from Canada, Germany, Iraq, Japan, Norway, Sweden, the UK and the USA. Some 180 British companies are showing at this exhibition.

NEW ZEALAND

Site decision awaited

The New Zealand Government is still undecided as to where the Nuclear Science Institute is to be located. The heads of the Otago University's physics and chemistry departments have stated that if, as proposed, the institute is built on the DSIR's Gracefield site, a public health hazard might be created. The government is now awaiting an assurance from the Radiological Advisory Council that complete safety can be achieved—so far, this assurance has not been given.

NORWAY

Power for the capital

A design study is being undertaken for a nuclear power plant to supply Oslo. For this project the Norwegian industrial nuclear group, NORATOM are cooperating with the Government's atomic energy institute at Kjeller.

America helps

This coming summer work will commence on the construction of the research reactor NORA, towards the cost of which the USA has made a $350,000 grant. All the component units will be fabricated in Norway.

RUSSIA

Ultra-high flux research

Work has started on the construction of an ultra-high flux reactor which will be used for the creation of and research into very heavy elements. With an extremely high flux it will be possible to create on a limited scale, the conditions that occur when a hydrogen bomb is exploded. Through the multiple-capture process, it would be possible to build up plutonium to element 98, californium. This reactor has been designed to have a neutron flux of 10^{15}n/cm^{2}s.

Electricity as a by-product

At the final meeting on March 23 of the 8th Mendeleyev Congress, Academician Anatoly Alexandrov reviewed the future use of nuclear energy. In a paper 'The Chemical Aspects of the Use of Atomic Energy' he said that within the next 10 to 20 years direct utilization of nuclear radiation would replace the present nuclear-thermal-electrical cycle and 'electrical energy will eventually become a

mere by-product'. A practicable application of this theory proposed that the radioactive waste from the nuclear power station now under construction near Voronezh could be used in irradiating motor tires during production.

Producing mobile units

Utilizing light water as the moderator and coolant, 2MW mobile nuclear power plants are being constructed in the USSR. The reactor, housed in a frame about 3½ ft in diameter and 7½ ft high, produces steam at approximately 250 psi and 280°C in the secondary circuit which is used to operate a turbine.

SPAIN

Power study initiated

With electricity consumption rising at a rate of more than 10% per annum and little water power remaining untapped, power production is one of the Spanish Government's main priorities in its industrialization programme. To achieve these plans, nuclear power generating stations will have to be constructed within the next five or six years.

The first stage in implementing this programme has been the recent signing of a nuclear study contract between the Junta de Energía Nuclear of Madrid and the atomic power department of Westinghouse. Studies will be made of a new type of reactor suitable for a proposed 20 MW power plant. The project is based essentially on the study and adaptation of a pressure tube reactor. This is an improved and modified heavy water-cooled and -moderated reactor in which the normal large pressure vessel is dispensed with and is replaced with a group of relatively small tubes. These contain the fuel elements through which the heavy water flows under pressure and acts as the coolant. The advantages of this type of reactor are that the maximum size of the power plant is not limited by the size of the pressure vessel and is more economical to fabricate.

Besides making the primary design study, Westinghouse, under the terms of the contract will investigate the general plant, fuel and site requirements.

UNITED KINGDOM

Biggest station yet

An application to develop a site of approximately 175 acres at Oldbury-on-Severn for a nuclear power station, is being made by the Central Electricity Generating Board to the Minister of Power and to the Local Planning Authority. There is every indication that this site would be suitable for a generating station having a total output of up to 1000 MW which could be connected to the 275,000 volt supergrid. A particular feature of this location is that advantage could be taken of a rock shelf off-shore to create an artificial tidal reservoir from which the large quantities of cooling water normally required for the steam turbine condensers could be drawn during low tide periods. This unusual formation would reduce substantially the costs normally incurred in making cooling water available where a great difference exists between high and low tide levels. Foundation conditions on shore are also very good and suitable for supporting heavy reactors.

Three other areas on the Severn Estuary are being investigated as to their suitability for future nuclear power stations; these are located at Tidenham, Aust and Portskewett.

Integration proposed

To extract the maximum possible benefit from the Hunterston nuclear power station, at present under construction, it is proposed to embody it with the new conventional steam powered plant at Kincardine, into the comprehensive Loch Awe pumped water storage hydro-electric scheme. The integration of nuclear and water power would reduce the capital cost of the nuclear portion from £150 per kilowatt to approximately £90 per kilowatt for the combined plant. The experience gained by this scheme will possibly be applied by the North of Scotland Hydro-electric Board and a second Scottish nuclear power station may be built in the far north as part of another pumped water storage scheme.

UNITED STATES

Direct steam production

A reactor, known as the Los Alamos Power Reactor Experiment No 2 (LAPRE II) achieved initial criticality on February 26. This is a unique homogeneous power reactor designed to produce superheated steam in one simple operation and is now being tested in the AEC's Los Alamos Scientific Laboratory, operated by the University of California —operational tests began on March 16. The purpose of LAPRE II is to determine the feasibility of using a solution of enriched uranium phosphate, phosphoric acid, and water as fuel, and relying on natural circulation of the solution to carry the heat to the heat exchanger where steam is produced. The reactor is designed to produce high pressure superheated steam suitable for modern electrical turbines and is expected to generate 1000 kilowatts of heat.

The heat exchanger for steam generation in the reactor is enclosed in the same pressure vessel as the reacting fluid. Because the fuel is extremely corrosive, gold cladding protects the structural metals which are in contact with the solution. The cylindrical gold-lined stainless steel pressure vessel is about four feet tall and has an inside diameter of 15 inches.

Criticality is achieved simply by inserting the liquid fuel in the reactor core. As the fuel temperature rises from 70°F to 800°F because of the nuclear reaction, the fuel expands 15 per cent. This expansion forces the uranium atoms apart which reduces reactivity until a stable temperature is achieved. When cold water is forced through the heat exchanger coils, heat is withdrawn from the fuel closest to the coils. This heat withdrawal causes the fuel to contract, drawing the atoms together, increasing reactivity and automatically compensating for heat loss. The fuel temperature remains essentially the same whether or not the heat exchanger is being used to generate steam.

The operational tests are being conducted to study the generation of superheated steam, response of the reactor to power demand, corrosion control by gold cladding of internal components, and radiation stability.

Other reactor developments in the design and/or construction stage, at this establishment, include LAMPRE (Los Alamos Molten Plutonium Reactor Experiment), and TURRET, a high temperature gas-cooled reactor using uranium-impregnated graphite. TURRET is designed to produce process heat rather than electric power.

New bomber project

The US Air Force announced on March 20 that the Convair (Fort Worth) Division of General Dynamics at Fort Worth, Texas, will work with the Nuclear Propulsion Division of the General Electric Company in the initial design of a nuclear-powered bomber prototype.

Preliminary design studies were made by the Marietta Division of Lockheed Aircraft Corporation and Convair-Fort Worth; in recent months the proposals of each of these companies has been carefully studied and the selection of Convair resulted from this evaluation.

While most of the current work on the aircraft nuclear propulsion programme is concentrated on the development of the propulsion system and will continue to be the case in the immediate future, it has been decided that more efficient use of the resources that are being invested can be realized if a single aircraft company works directly with the propulsion contractor in carrying out the design. This is a natural outgrowth of nuclear research that began at Convair-Fort Worth in 1951 and which included the design, construction and testing of the world's first flying nuclear reactor

in a modified B-36 bomber, the NB-36H.

The Air Force will continue to support limited design work by Lockheeds and their nuclear laboratory at Georgia will continue its studies into radiation effects.

Fitting out

The first US submarine designed to provide the 1500-mile-Polaris ballistic missile with a mobile underwater launching platform will be launched on June 9 at General Dynamics Corporation's Electric Boat Division yards, Groton, Conn.

Named 'George Washington' the SSB(N)598 is a 380-foot, nuclear powered submarine of about 5400 tons light and 6700 submerged. It has vertical tubes for firing the solid-fuelled Polaris missiles when below or on the surface, and will be complemented by a torpedo-firing system for attacking surface ships or enemy submarines. This large missile vessel will be equipped with SINS (Ships Inertial Navigation System) and with these potentials, the 'George Washington,' together with her sisterships, will be one of the nation's prime deterrents to aggression. The 'George Washington' is scheduled to become operational in 1960, when the solid-propelled, inertially guided Polaris will also become operational.

Medical reactor goes critical

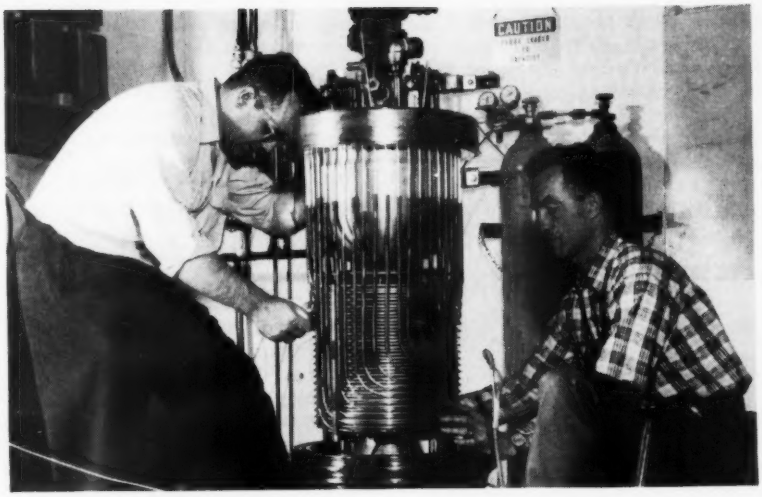
The Medical Research Reactor (MRR) at Brookhaven National Laboratory reached criticality on March 15. This tank-type reactor, of 1 MW nominal operating power level, is the world's first designed specifically for medical use and is installed in the new medical research centre. This establishment, in addition to the reactor facilities, includes a hospital and extensive medico-nuclear laboratories.

Uranium output boosted

The AEC and Federal-Raderock-Gas Hills Partners, of Salt Lake City, signed a contract on April 10 for the sale of uranium concentrates to the Commission. This will necessitate the construction and operation of a new processing mill in Fremont County, Wyoming, which will have a capacity of approximately 522 tons of ore per day. Construction, costing some $M3, is starting immediately and should be completed within twelve months.

AEC are continuing negotiations with three other Wyoming firms and which may result in the expansion of two existing mills and the construction of another new mill.

The Grand Junction operation office of the AEC report that in 1956 over 3M tons, in 1957 more than 3½M tons and the first six months of 1958 2,341,791 tons of uranium ore was produced. The output continued to rise in the second half of 1958, when 2,807,000 tons of ore was received. During 1956 the U_3O_8 content was 0·28% but during the first half of 1957 it was only 0·27% and dropped to 0·26% in the second of the year. In the first half of 1958 the U_3O_8 content was running at 0·28% but by the end of the year it had fallen to 0·255%.



FINAL ASSEMBLY OF THE LAPRE II. The gold-clad heat exchanger is lowered into the gold-lined pressure vessel. On the left is Robert A. Clark, head of the LAPRE II project and on the right is James A. Bridge, the engineer in charge of building the heat exchanger

Fuel cycle development

The AEC has selected as a basis for contract negotiation, 24 proposals from 18 firms to undertake research and development in the Commission's fuel cycle programme. These proposals were selected from 111 received from 39 firms in response to an invitation issued last October to industry and research institutions to participate in a programme to improve the fuel cycle for nuclear power reactors.

More isotopes

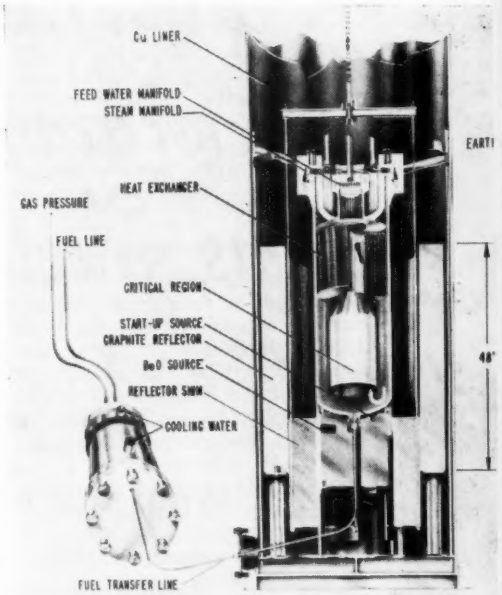
A total of 228,171 curies of radioisotopes were shipped from AEC's Oak Ridge National Laboratory during 1958 and represents an increase of 37% over the previous year's shipments.

Libby goes

After nearly five years of continuous service with the AEC Dr. Willard F. Libby is resigning from the agency on June 30.

The deputy general manager of AEC Paul F. Foster has been nominated by President Eisenhower to be the US representative to the IAEA.

New York State has created an office of Atomic Development to watch its interests in the increasing industrial adoption of nuclear engineering. Mr Rockefeller, the State Governor, has nominated Mr Oliver Townsend, former assistant to the AEC, as the Office's first director.



Schematic drawing of the LAPRE II reactor which produces superheated steam in one operation

Awaiting results

The Great Lakes section of the Society of Naval Architects and Marine Engineers have proposed that nuclear-powered vessels are kept off the Great Lakes until more is known about their operating conditions. These will be studied at the International Safety of Life at Sea Convention in London next year.

Applications for ceramics in nuclear energy are increasing and further development of high temperature reactors will depend on them to a great extent. This two-part feature gives an introduction to ceramics in general, and then reviews the data now available on the materials being developed to replace metallic fuels

The future of Ceramics as nuclear fuel

1. What are ceramics?

by N. C. MOORE *and* J. B. HUFFADINE

Caswell Research Laboratories, The Plessey Co Ltd

THE WORD CERAMIC has associations with the pottery industry but during the past few decades its meaning has broadened until it now includes almost all non-metallic polycrystalline bodies fabricated from a powder by the application of heat.

The most generally used process is one in which powder compacts are heated to a sufficiently high temperature to convert them into dense bodies without melting occurring. This is known as sintering.

The wide range of ceramic materials may be sub-divided into two classes:

1. Simple ceramics consisting of a single chemical element or compound, for example, pure oxides, sulphides, carbides, borides, nitrides, silicides and graphite
2. Composite ceramics composed of a mixture of two or more different elements or compounds of which one may be metallic; under this heading come certain glass-bonded materials and cermets such as chromium-alumina and the metal-bonded carbides.

Apart from the obvious effect of the intrinsic properties of the constituent material, the mechanical properties of a ceramic body are influenced to a marked degree by grain size and porosity. In general, the finest grain and lowest porosity give the strongest body. In the case of the simple ceramics, it is often difficult to eliminate all porosity. Thus a material which exhibits a negligible water absorption may still contain a number of closed pores. In the composite ceramics, where there is frequently a small amount of liquid phase present during sintering, porosity may be almost completely eliminated. This is believed to be the reason for the high cross-breaking strength of the metal-bonded carbides (>200,000 psi) as compared with that of the self-bonded ones (<100,000 psi).

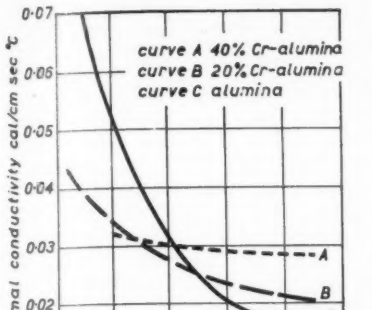
All present-day ceramic materials are brittle in comparison with metals and most of them are comparatively hard. Owing to their brittle nature, unavoidable surface imperfections result in low tensile strength. Their compressive strength on the other hand is high. For example a high grade alumina with a tensile strength of 30,000–40,000 psi at 20°C might have a compressive strength as high as 240,000 psi at the same temperature.

The thermal expansion coefficients of most simple ceramics are lower than those of the more commonly used metals and lie in the range of 0–10 $\times$ 10^{-6}/°C. This fact has to be borne in mind when using ceramics in conjunction with metals, particularly when large temperature changes are likely to be encountered. In composite materials the thermal expansion is usually determined by the major phase when this is present in sufficient volume to be continuous. If, however, the various phases are present in more or less equal volumes, it is not possible to predict the expansion coefficient with any degree of certainty.

The thermal conductivity of simple ceramics varies from very high values for certain graphites (0·6–1·0 cal/cm sec °C) and beryllium oxide (0·6 cal/cm sec °C) to very low values (0·002 cal/cm sec °C) in the case of certain insulating refractory bricks. In the case of simple materials the thermal conductivity falls with increasing temperature but in the composite materials such as cermets this effect may be much reduced or even reversed, as shown in figure 1.

Cold compaction and sintering

The starting material in the preparation of ceramic bodies is a powder, the particles of which are made to cohere by the application of heat. The process is facilitated if the par-



The fall in thermal conductivity with temperature common in simple ceramics is reduced or even reversed in cermets (Fig 1)

ticles are packed together closely prior to the sintering operation and several methods are available for achieving this. Thus the powder, with or without an admixed binder, may be subjected to pressure in a steel die. The pressure required for suitable compaction varies according to the powder properties but the shape of the pressure-compaction curve is similar to that shown in figure 2. Unlike metals, most ceramic particles are not deformed by pressing and the maximum useful pressure is that beyond which no appreciable further compaction occurs. Very fine powders frequently yield cracked compacts but various techniques have been developed to overcome this effect.

When complex shapes are pressed in steel dies, pressure gradients occur in the powder and give rise to distortion during the subsequent sintering operation. This may be minimized by isostatic pressing in which the powder is enclosed in a flexible mould and subjected to hydrostatic pressure. Since pressure is then applied equally in all directions a more uniform compact is achieved than is possible in a steel die. Alternatively, pressings formed in a steel die may be subsequently enclosed in a rubber bag and subjected to hydrostatic pressure. A further modification of this process has been described in which a reversible gel in a steel container acts as both mould and pressure transmitting medium (*1*).

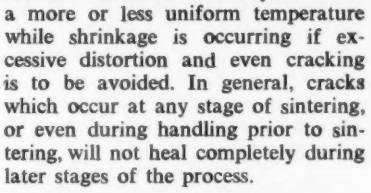
Slip casting

In order to avoid pressure gradients, the slip casting method may be employed. In this process a 'slip', which consists of a suspension of the ceramic powder in a suitable liquid medium, is poured into a plaster-of-Paris mould. The liquid is absorbed by the plaster-of-Paris and the ceramic powder takes up the shape of the mould cavity. This process is particularly suitable for the preparation of thin-walled hollow shapes since surplus slip may be poured out from the mould as soon as the deposited layer has reached the desired thickness. After drying the 'casting' is removed from the mould and fired.

In addition to the above methods extrusion processes are employed, particularly for forming rods and tubes. The ceramic powder is mixed with sufficient binder to form a plastic mass which, after being carefully 'deaired', is forced through a suitable die. As in all extrusion processes, there is a tendency for anisotropic particles to be aligned and in such a case the properties of the resultant ceramic may be directional.

The conversion of a porous fragile powder compact to a dense, strong, ceramic body is accomplished by a sintering or firing process. The compact is placed in a furnace and heated to a temperature below its melting point for a suitable period. Shrinkage then takes place and the body becomes less porous, the process being dependent on both time and temperature.

At the temperatures required for adequate sintering, a process of grain growth frequently occurs and since this tends to impair the mechanical properties of the fired body, sintering schedules must be such as to minimize it. Thus the lowest possible temperature may be used for a long period or the compact may be taken to a higher temperature for a very short time. The use of high temperatures for short times is limited by the necessity for the whole of the body to be at a more or less uniform temperature while shrinkage is occurring if excessive distortion and even cracking is to be avoided. In general, cracks which occur at any stage of sintering, or even during handling prior to sintering, will not heal completely during later stages of the process.



Pressure/compaction curve for a ceramic powder is typical of most materials (Fig 2)

In addition the grain size of the sintered body is partly determined by that of the original powder. Thus a coarse powder yields a coarse grained material and fine powder yields a fine grained material. When an ultrafine powder is used, however, a non-uniform texture containing a number of coarse grains may result owing to the readiness with which grain growth occurs in such conditions.

Sintering atmosphere critical

In order to avoid change in the chemical composition of the ceramic the atmosphere in the sintering furnace must be suitably controlled. Most oxides may be fired in air but certain lower oxides, for example, uranium dioxide, must be fired in a non-oxidizing atmosphere if conversion to the higher oxide (U_3O_8) is to be avoided. Owing to the high temperatures required for sintering and the large surface area of the porous compact, comparatively small proportions of impurity in the furnace atmosphere may have a great effect on the properties of the fired material, or may prevent sintering from occurring. Thus certain silicides will not sinter in an atmosphere containing small amounts of carbonaceous gas owing to the formation of thin films of silicon carbide on the surface of each particle of powder. Similarly the presence of a small quantity of water vapour in an otherwise inert atmosphere will frequently cause oxides to appear in non-oxidic ceramics.

As mentioned previously it is usually desirable that heating should be carried out at such a rate that the whole of the body to be sintered is at a substantially uniform temperature. This necessitates the provision of fur-

These use oxide

Following the successful use of oxide pellets for blanket elements in the Shippingport pressurized water reactor, all American pressurized and boiling types now under construction will use this form of fuel. These include: Indian Point, Yankee and APPR1 ***(pressurized); Dresden, Sioux Falls, the NS*** Savannah, ***Kahl (Germany) and Punta Fiume (Italy) (boiling). The Soviets are also using oxide in their pressurized types—including the*** Lenin ***icebreaker—and Canada has chosen it for her first power reactor the*** NPD-2. ***In Britain uranium oxide elements will be used in the Advanced Gas-cooled reactor at Windscale. This 28 MWe power experiment is expected complete early in*** 1961.

naces of sufficient size to accommodate at least one component. A process described as zone sintering has, however, been developed in which a long extruded rod is drawn through a furnace with a comparatively short hot zone, sintering occurring as illustrated in figure 3 (2).

Fabrication by hot pressing

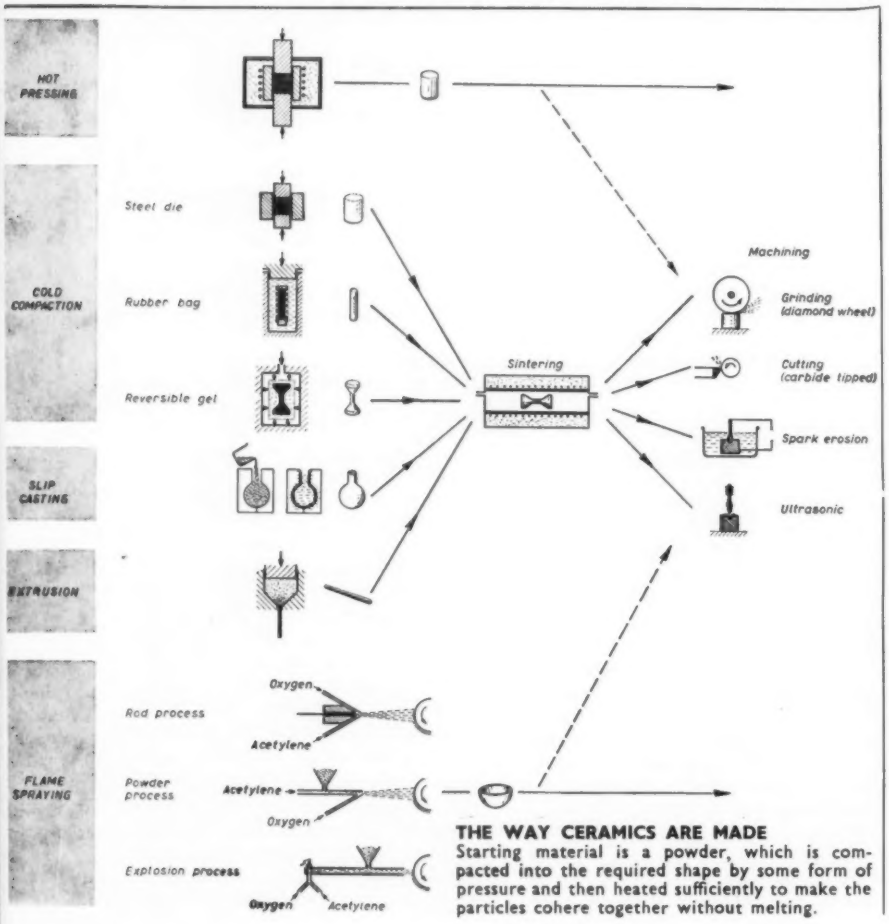
Owing to the shrinkage which occurs during sintering of cold pressed compacts, it is difficult to achieve close mechanical tolerances particularly in the case of large parts. Machining of the fired ceramic frequently involves diamond wheel grinding which is both slow and costly. Hot pressing provides a way of minimizing this difficulty. In this process the ceramic powder is placed in a heated graphite die and compressed while hot. All the shrinkage then occurs in the direction of pressing and much closer dimensional control is achieved. The temperature required for satisfactory hot pressing is approximately that required for sintering the same material but the time is very much reduced—in some cases by a factor of 10 or 20. The pressure employed is usually about 1 ton per square inch, this being well within the strength of the graphite at all temperatures up to 2500°C.

Although graphite hot pressing dies and punches are comparatively cheap and easy to fabricate, their use gives rise to certain problems. Owing to the softness of the die material, abrasion occurs as each ceramic compact is extracted and only a few satisfactory pressings may be obtained from each die. Since the hot pressing operation is usually carried out in air, the hot die cavity contains oxides of carbon which may react with the ceramic material. The extent of such reaction can be minimized by employing as high a pressure and rate of heating as possible. This results in early closure of the pores in the ceramic and prevents excessive diffusion of gaseous contaminants.

Coating by flame spraying

Flame spraying methods are being used to an increasing extent for applying ceramic coatings to various bodies. Basically the process consists of projecting a stream of droplets of molten ceramic on to a surface where they solidify and build up a coating. The droplets are produced in various ways, thus one process fuses the end of a ceramic rod by means of an oxyacetylene flame and atomizes and projects the liquid by means of compressed air. In another process ceramic powder is carried on a stream of acetylene into an oxyacetylene flame where the particles are melted, and projected by the combustion gases on to the surface to be coated. A third process makes use of the flame front from an exploding acetylene-oxygen mixture to melt and project the ceramic particles at high velocity on to the surface.

Generally speaking, flame-sprayed coatings have a porosity of between 5 and 10% but values as low as 1% are claimed for the explosion process.



THE WAY CERAMICS ARE MADE
Starting material is a powder, which is compacted into the required shape by some form of pressure and then heated sufficiently to make the particles cohere together without melting.

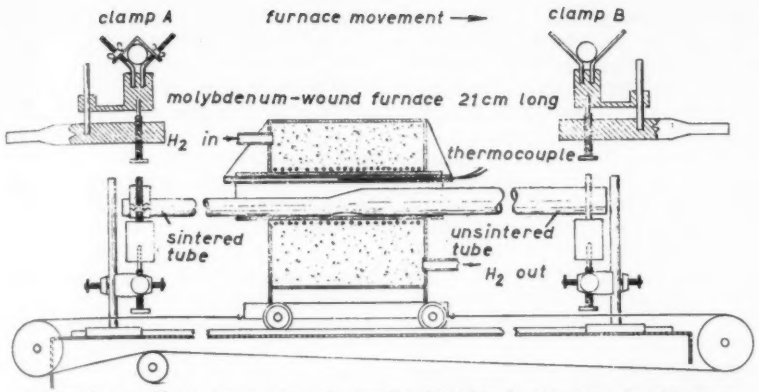
Special machining techniques needed

The linear shrinkage which takes place during the sintering of a pressed powder compact may be as high as 20% and varies slightly over the component. It is thus difficult to produce a fully sintered part to a close mechanical tolerance. Sometimes a double sintering process is used to permit a closer approach to the required dimensions. This involves partial sintering of the powder compact at a temperature below the sintering temperature, machining the resultant chalky body and then sintering at the temperature required to yield a dense material. Shrinkage during the second firing may be only 5% and greater dimensional accuracy in the fired part is obtained.

When, however, engineering tolerances are required, the sintered part must be subjected to some form of machining process. With comparatively few exceptions ceramic materials, particularly those with valuable high temperature properties, are hard and brittle and demand special techniques. Probably the most common technique is the use of diamond impregnated tools which may be used for cutting, surfacing and drilling. Such methods are necessarily expensive and spark erosion or ultrasonic machining processes may be preferred.

In the spark erosion process, which is applicable only to electrically conductive materials, stock is removed by making the work one of the electrodes in a properly designed circuit. Rapidly pulsed current of the spark discharge type is then passed between the work and the other electrode, both of which are immersed in a dielectric fluid.

Ultrasonic methods are applicable to all brittle materials whether electrically conductive or not. A suitable tool is oscillated at ultrasonic fre-



Although a uniform temperature is usually desirable in sintering, in this zone sintering furnace for extruded rod there is a comparatively short hot zone (Fig 3)

quency in close proximity to the work and an abrasive slurry is fed between the two. Provided that the tool is softer and the abrasive is harder than the work, particles of abrasive become embedded in the tool and cut the ceramic.

Among the more readily machinable ceramics are graphite and boron nitride, both of which may be readily worked with carbide tipped tools although frequent resharpening is required in the case of graphite in spite of its apparent softness. Certain of the high metal-content chromium-alumina cermets may also be machined with carbide tools provided that care is taken to avoid chipping at the edges of the materials.

Design considerations

Owing to the large shrinkage which occurs during sintering it is difficult to hold dimensional tolerances to better than about $\pm 3\%$. This figure depends on the size and shape of the part and whether it is hollow or not. The use of hot pressing methods where applicable permits the achievement of greater accuracy. Parts may of course be finished to standard tolerances by machining or grinding.

When parts are to be produced by cold pressing and sintering, it is desirable that they should have a flat surface on which to stand during firing. Abrupt changes of section should be avoided as these introduce complications in die design and may lead to distortion during sintering. Sharp corners should also be avoided in order to reduce stress concentrations to a minimum and radii on corners and in fillets should be as large as permissible.

The size of components should be kept to a minimum since small parts are more readily fabricated than large ones. When large parts are required it is recommended that where possible these should be built from a number of pieces.

Should the component be needed in a location where heating is likely to occur, care should be taken to see that, under service conditions, tensile thermal stresses do not appear in thin section regions. A crack, once initiated, will spread rapidly.

Joining ceramics to metals

Most of the electrically conductive ceramics such as bonded carbides and cermets may readily be joined to metals by standard brazing methods, but special techniques are necessary in order to effect a bond between metals and the electrically insulating ceramics. In addition to mechanical keying, these techniques in general rely upon the provision of an intermediate material capable of bonding both to the ceramic and metal. A number of such processes have been developed for specific materials.

Although most ceramics can be joined to metals by the application of a suitable technique, unless the part is correctly designed and the thermal expansion coefficients of the components bear the correct relationship, the joint is likely to fail. The design should be such that at no time either during assembly or subsequent service is the ceramic part or the joint subjected to tensile stress.

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The future of Ceramics as nuclear fuel

2. Development of the new fuels

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THE CERAMIST engaged in nuclear energy research has to consider at some time or other most of the commercial refractory materials, but to date his work has been chiefly concerned with refractory compounds which have been little studied in the past. These include the dioxides of uranium, thorium and plutonium, their carbides, and mixtures or dispersions of these materials in matrices of other metallic or ceramic materials.

These materials are of use as fuels in place of the respective metals and their application, initially at least, will represent the first major introduction of ceramic type materials other than graphite into power reactor systems. At a later stage it is likely that the metal can, which serves to retain the products formed by fission within the fuel element and hence to prevent contamination of the coolant circuit, may be replaced by brittle materials of the more conventional type such as graphite, alumina and beryllia. The behaviour of ceramic materials of both types described above under neutron bombardment as occurs in service in reactors is therefore of considerable interest and introduces a completely new problem.

URANIUM DIOXIDE

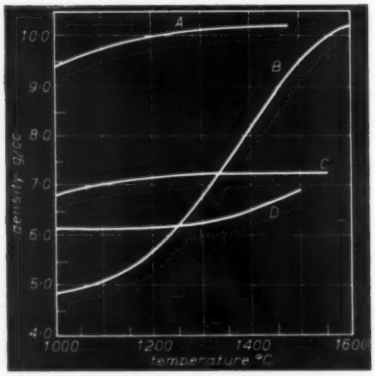
Uranium dioxide is attractive as a reactor fuel because of its good irradiation stability and its relative chemical inertness towards many coolants such as hydrogen, water and CO_2. It has a high melting point and is strong at temperatures up to at least 1000°C. As is inevitable, there are certain disadvantages in its use as a fuel. Since it is brittle and cracks due to thermal stresses, the strength of the fuel element must be largely supplied by the

can; in this respect it differs from uranium metal which may itself provide the structural part of the fuel element up to about 500°C, the can merely serving to retain fission products. Since aluminium and magnesium are too soft above 400–500°C, they cannot be used to contain uranium dioxide fuel at can surface temperatures above this. The only metal of low neutron capture cross-section which might therefore be used for higher temperature service is beryllium. In addition uranium dioxide has a poor thermal conductivity, particularly at temperatures above 1500°C, and although this is somewhat offset by its high melting point, it does introduce a restriction in the design of fuel elements. In particular, to avoid centre melting the use of fuel elements of small diameter is necessary and a larger amount of canning material is required.

Two compositions present

When higher oxides of uranium are reduced in hydrogen the structure of the powder so prepared is stoichiometric $UO_{2\cdot0}$, but when the powder is exposed to air at room temperature the oxygen content increases by an amount which depends mainly on the particle size of the powder but also on the time of exposure. Equilibrium structures are developed by holding the material so produced in the absence of air at temperatures of 300°C and above. At about 300°C, oxides in the composition range UO_2 to U_4O_9 consist of mixtures of the two phases having the compositions UO_2 and U_4O_9. As the temperature is raised, the oxygen content of the UO_2 increases while that of the U_4O_9 decreases. For example, UO_2 goes to $UO_{2\cdot05}$ at 450°C and to $UO_{2\cdot15}$ at 850°C. At the sintering temperatures normally employed, oxides in the range UO_2 to U_4O_9 generally consist of a single phase which on cooling will again break down into the two phases based on UO_2 and U_4O_9 if the composition lies between these two extremes. UO_2 has a cubic calcium fluoride structure; U_4O_9 has a similar structure with the extra oxygen atoms in interstitial positions. Thus sintered specimens will consist either of stoichiometric UO_2 or two phase mixtures of UO_2 and U_4O_9. The custom has developed of calling the latter room temperature, two-phase structure, non-stoichiometric uranium dioxide.

Uranium dioxide powder can be prepared by the reduction of a higher oxide such as UO_3 with hydrogen in the temperature range 500–800°C and the powder particles obtained in this way are agglomerates of crystallites. The particle size and crystallite size of the uranium dioxide are functions of the characteristics of the higher oxide and of the reduction temperatures. The higher the reduction temperature the greater the particle size and crystallite size of the powder produced. As reduced the composition is $UO_{2\cdot0}$. UO_2 powders will oxidize in air at low temperatures (18–100°C). Powders with particle sizes in the region of 1 micron will generally oxidize to compositions of about $UO_{2\cdot02}$ after an exposure of 1 month at room



Effect of sintering temperature and atmosphere on density of two types of uranium dioxide. Curves A and B are for $UO_{2\cdot24}$, C and D for $UO_{2\cdot04}$, in argon and hydrogen respectively (Fig 4)

temperature. Smaller particle size preparations in the range 0·1 micron particle size oxidize more rapidly and may heat up so violently that partial conversion to U_3O_8 occurs.

Several methods can be used to formulate the characteristics of the powders, primarily for control purposes:

a. The surface area can be measured by nitrogen absorption or by gas permeability methods. In relation to reactivity and its effect on subsequent sintering behaviour the former method, although more time consuming, gives an answer nearer the truth since the application of the Kozeny relation (on which the gas permeability method depends) to this type of fine agglomerate powder is theoretically doubtful. Empirical correlations can however be obtained between nitrogen absorption and gas permeability measurements on uranium dioxide powders and the more rapid gas permeability method used for control of batches of powder.

b. Attempts have also been made to use differential thermal analysis curves obtained on heating uranium dioxide powders in air or oxygen to characterize the powder. While general trends are apparent between the temperatures of the peaks on DTA curves and the reactivity of the powder, there is lack of quantitative agreement between different laboratories.

c. The change in oxide composition under standard storage time and conditions is a useful and quick way of indicating reactivity and it is surprising it is not used more widely for the characterization of high surface area powders.

Generally surface area determinations, preferably by nitrogen absorption, determination of the oxide composition and specific gravity, form suitable criteria for defining the characteristics of uranium dioxide powders.

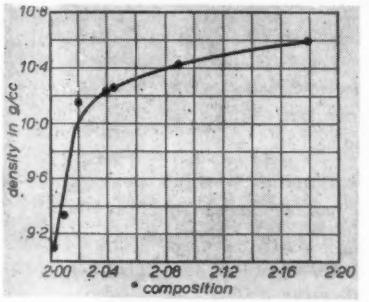
The main technique for preparing solid UO_2 from powder is that of cold compacting followed by sintering in a controlled atmosphere and studies of the sintering behaviour of non-stoichiometric oxides have uncovered some interesting aspects of the sintering process. Initially two types of powder from two different sources were investigated with the results shown in figure 4. The compacts were all prepared by cold pressing in metal dies at 10 tons/in² followed by sintering at the various temperatures shown for 2 hours in atmospheres of both argon and hydrogen.

Effect of oxygen content

There is a major difference in behaviour between the two types of oxide and in addition sintering atmosphere plays a significant part in determining the bulk density obtained under a given set of conditions. As indicated, the two oxides differed in oxygen content and as hydrogen is known to reduce the oxygen in excess of stoichiometric at temperatures of 500°C and above, it is plausible to attribute the enhanced sintering behaviour of the higher oxygen content oxide solely to a large departure from stoichiometry. However, particle size also plays an important part in determining sintering behaviour: the smaller the particle size the more readily sintering occurs. When the surface areas of the two powders were determined the one of lower oxygen content had a value of 0·2 m²/g and the other oxide approximately 8 m²/g as determined by the nitrogen absorption method. The possible effects of particle size and excess oxygen are therefore interrelated, and as the particle size of one of the oxides was approximately 40 times smaller than that of the other, its enhanced sintering behaviour could possibly be attributed entirely to this feature without involving explanations based on departure from stoichiometry.

To separate the effects of these two

variables uranium dioxide powder of high surface area was prepared in an inert atmosphere to stoichiometric composition and then allowed to oxidize slowly at room temperature in air. Samples of different oxygen content were then cold compacted and given a standard sintering treatment of 2 hours at 1450°C in argon. In this way the relationship between oxygen content and sintered bulk density shown in figure 5 was obtained, the particle size remaining sensibly constant during the oxidation process. These results indicate that departure from stoichiometry plays a definite part in the sintering of the oxide, although the mechanism by which the extra oxygen operates to aid sintering cannot be stated definitely. If a diffusion mechanism is responsible for sintering, the rate of change of density will be determined by the slower of the two ionic diffusion rates. The diffusion rate of the oxygen in excess of the stoichiometric amount is known to be extremely rapid so that the cation diffusion rate will probably be rate determining and



Cold compacted samples of uranium oxides, sintered for 2 hours at 1450°C in argon, showed this relation between density and oxygen content (Fig 5)

must therefore in some way be affected by the departure from stoichiometry to explain the observed sintering results.

Several ways of sintering

As a result of the effects of particle size and non-stoichiometry, many variations in sintering procedure are possible, thus:

1. High surface area, non-stoichiometric oxide can be sintered directly in hydrogen, the product being $UO_{2\cdot0}$; temperatures of 1600–1650°C are necessary to obtain high bulk densities (~ 95% theoretical)

2. The same type of oxide can be sintered in an inert atmosphere of nitrogen or argon at 1450°C to similar bulk densities; for the product to be $UO_{2\cdot0}$, the atmosphere has to be changed to hydrogen either at temperature or during the cooling cycle

3. Steam can be used as the sintering atmosphere with $UO_{2\cdot0}$ powder again followed by a change to a reducing atmosphere of hydrogen.

By any of these variations in procedure very dense compacts or shapes can be obtained.

Fuel elements can also be made directly by the swaging of high packing density powders, usually prepared from fused UO_2 in zircaloy or stainless steel tubes. The bulk density of the oxide obtained is generally lower (~ 90% theoretical); as yet indications are that the irradiation behaviour and performance of the lower bulk density material is not significantly worse than the higher bulk density sintered UO_2 in cases where thick-walled zircaloy cans are used. With

TABLE 1 Data on thermal conductivity of $UO_{2\cdot0}$ (K in cal/sec °C cm²)

TEMPERATURE °C	MIT DATA	ARMOUR RESEARCH DATA	AERE DATA
200	0·018	0·0125	—
400	0·013	0·0090	—
600	0·010	0·0080	—
800	0·0084	0·0065	0·0078
1000	0·0078	0·0055	0·0062
1200	—	0·0050	0·0058
1400	—	0·0045	—
1600	—	0·0045	—

thin-walled stainless steel tubes, however, the position could be radically different in that minimal fission gas release is required and this in part is a function of bulk density and microstructure. It is also very doubtful whether the swaging technique could be used with beryllium.

The thermal conductivity is an important parameter and typical data is given in Table 1. The expression, $K = 10D\ (T + 400)$, where D = density expressed as a fraction of theoretical density (10·96 g/cc) and T is in °C, fits the data given within the experimental error of any of the determinations. These values can be used in conjunction with other properties of UO_2 in thermal stress equations to predict the heat flux conditions at which cracking of the UO_2 will occur under irradiation, assuming no effect of irradiation on K. It is found that if UO_2 is subjected to a heat flux greater than 40 W/cm² thermal shock will occur.

The room temperature bend strengths of uranium dioxide lie in the range 10,000–16,000 psi and there is little reduction in strength between room temperature and approximately 1000°C. There is an effect of grain size in the stoichiometric case in that stoichiometric UO_2 prepared by sintering the non-stoichiometric oxide in argon at 1450°C, followed by a hydrogen reduction at a lower temperature of 1200°C, has a higher bend strength than the stoichiometric material prepared by sintering at the higher temperature of 1700–1750°C. In the former case the average sintered grain size is 1–20 microns, whereas that of the higher temperature sintered material is closer to 50 microns. This result is qualitatively in agreement with theory, although as yet there is insufficient data to support the theoretical implication that the strength should vary inversely as the square root of the grain size. Values close to 25×10^6 psi have been obtained for the elastic modulus of uranium dioxide at room temperature.

With respect to compatibility with coolants, in air hot pressed or sintered UO_2 of high bulk density has a negligible rate of oxidation up to 300°C (0·3 mg/cm²h at 300°C). The rate increases rapidly up above 300°C to reach a maximum of 160 mg/cm²h at 700°C; thereafter the rate of oxidation decreases, probably due to the onset of sintering of the surface layers of U_3O_8. In wet and dry CO_2 the rate of oxidation of UO_2 is very much slower than that of uranium metal in the temperature range 500–900°C.

Behaviour under irradiation

The bulk of the irradiation data available is on $UO_{2\cdot0}$ from experiments in pressurized water loops, at can surface temperatures of 280–325°C. Although there is disagreement in detail the broad features are as follows:

1. In sharp contrast to the behaviour of uranium metal, UO_2 does not swell or expand to any measurable degree

2. Radial cracking occurs at a very early stage in the irradiation due to thermal stresses arising from the very high temperature gradients

3. Melting in the fuel can occur resulting in the formation of a central pipe, either if the diametral clearance between fuel and sheath is too large or if the fuel diameter is too big for a given concentration of uranium-235 and corresponding heat output

4. Attempts have been made to analyse the irradiation results in the cases where centre melting has occurred and these indicate that the thermal conductivity under irradiation is not very markedly reduced

5. There is a fairly good correlation between release of fission gases from the UO_2 and the centre temperature: if central melting occurs there is a large release of fission gases compared with the case where melting has not occurred. Isolated experiments have shown that the bulk density of the UO_2 is also important, more gas being released when the fuel is porous

6. For given irradiation conditions the

fission gas release from non-stoichiometric oxide is very much higher than that from UO_{2-0}, probably due to a breakdown of the former at high temperatures into two phases, one of them being volatile UO_3; the fully reduced oxide therefore gives the better irradiation performance.

URANIUM MONOCARBIDE

Uranium monocarbide is similar in structure to most of the hard metal monocarbides having a sodium chloride structure, but differs from them in having only a moderate hardness of about 800 VPN. It has a melting point of 2400°C and a theoretical density of 13·63 g/cc.

Shapes may be made from uranium carbide powder by the standard technique of cold compacting and sintering. The carbide powder can be prepared in several ways. The reduction of uranium dioxide with graphite in vacuo at 1800°C will yield lumps of monocarbide which can then be comminuted mechanically. Uranium metal can also be carburized via the hydride in various gaseous hydrocarbons at about 650°C to give monocarbide powder directly. The sintering temperatures needed to obtain 85% theoretical density, starting with the compacted powder prepared by either of these two routes, vary from 1800–2000°C. By reducing the particle size of the carbide the sintering temperatures are approximately 1800°C. The monocarbide is a material which oxidizes very readily, the fine powder is pyrophoric and consequently handling must be carried out in protected atmospheres in glove boxes. A neutral atmosphere is therefore essential for sintering and both argon and vacuum have been employed.

It is also possible to prepare uranium carbide shapes of bulk densities of 85–90% theoretical by reacting the stoichiometric amounts of uranium and graphite powders in the solid state at about 1050°C. Only minor volume changes accompany this reaction and the bulk density of the uranium/graphite mixture before sintering must therefore be made as high as possible; this can best be achieved by hot consolidation, either by compacting or extrusion. Hot compacting of the uranium/graphite mixture can be carried out over a range of temperatures from 650°C up to 800°C under loads varying from 10–20 tons/in². The highest densities are obtained at the higher temperatures when the uranium is in the plastic gamma range. The uranium/graphite mixture may also be hot extruded in a manner similar to uranium metal powder, but it is advisable to use temperatures in excess of 800°C as considerable cracking occurs at lower temperatures. Protective atmospheres of either vacuum or argon have to be used in reacting the consolidated uranium/graphite mixture, and reasonably large pieces of carbide of 90% theoretical density have been made in this way. Uranium and graphite powders may also be cold compacted to high densities and when such compacts are sintered at 1050°C *in vacuo* bulk densities of about 10·5 g/cc can be obtained. UC can also be fabricated on a small scale by fusion casting.

Advantages over UO_2

The mechanical properties of sintered uranium carbide are superior to those of UO_2; for example the room temperature bend strength of UC is approximately three times that of sintered UO_2. In addition the room temperature thermal conductivity is 2–3 times that of UO_2 and would be expected to decrease much less sharply with temperature than that of UO_2 since the conduction would tend to be electronic rather than ionic. There is the possibility therefore that larger diameter rods or thicker plates could be used than in the UO_2 case under similar heat ratings, and a substantial economy could be obtained in the amount of canning material required per unit of fuel.

This advantage could be offset to some extent by the lower melting point of UC if the fission gas release-temperature relations are similar for both materials. Small scale irradiations of 2 mm diameter pins of UC have been carried out and it has been found that cracking occurs with the release of up to 10% of the fission gases after 3000 MWd/t burnup at 630°C. On general grounds one would expect little difference in behaviour of UC and UO_2 in relation to volume stability and cracking on irradiation since both are brittle materials. The question of fission gas release from UC is unresolved although on the above initial results it is worse than

CERAMICS WITH NUCLEAR POTENTIAL

*With **bulk uranium dioxide** there are large differences in the fabrication, properties and irradiation behaviour caused by variations in the oxygen content. Use may be made of non-stoichiometry as an aid to sintering; the irradiation results obtained so far indicate that the non-stoichiometric material is not so satisfactory as a fuel as stoichiometric uranium dioxide.*

*While **uranium monocarbide** has more attractive thermal and mechanical properties than uranium dioxide, its chemical compatibility with coolant gases such as CO_2 leaves much to be desired. The irradiation behaviour of uranium monocarbide needs more detailed investigation before comparison can be made with that of uranium dioxide.*

*With **dispersed fuels** unless metals of high neutron absorption cross-section can be accepted there are no metallic matrices that will offer a fuel element capable of prolonged operation above 600°C. Of the oxide matrices beryllia and alumina appear the most attractive. Much more data is required on the effect of neutron irradiation and fission product damage at high temperatures on the properties of these materials. Graphite is an admirable dispersion medium for fissionable carbides but must be impermeable to prevent release of fission products at high temperatures. Of the carbides silicon carbide offers possibilities as a matrix for a disperse fuel element; data is required, however, on the phase equilibria in the system USiC before a more realistic assessment can be made.*

for UO_2. The present density levels achieved in the fabrication of UC are also lower than with UO_2 and may be in part responsible for the above gas release. The need exists, therefore, for higher density fabricated UC and in addition both the effect of the density and grain size on fission gas release needs investigation.

UC in either powder or sintered form oxidizes readily in air at moderately low temperatures. As regards compatibility with CO_2 the results obtained show that the behaviour of UC is worse than that of uranium at 500°C but that at 700°C the order is reversed. In fact the rate of oxidation of UC by CO_2 is practically invariant with temperature in the range 500–830°C. It is felt that this is connected with the physical effects such as sintering of the oxide skin formed on the carbide.

DISPERSION-TYPE FUELS

Dispersion or cermet type fuel elements can be defined as elements in which the fissionable phase is dispersed in a matrix material which will usually be non-fissionable but may be fertile. Such dispersion elements have been described as possessing two unique advantages over homogeneous elements: long life because of localization of fission product damage, and increased choice of structures. Of the fissionable compounds that may be of interest as dispersants, those of the highest uranium density, with the exception of the hexavalent uranium compounds and U_3Si, are those which can be classed as ceramics.

It is necessary to use highly enriched fuel with dispersion-type elements. If a plutonium recycling scheme is adopted it may be advantageous to incorporate the plutonium in a dispersion-type spike fuel element and obtain a high burnup of the fissionable material. The case for a dispersion fuel based on highly enriched uranium ceramics is more difficult to make as will be evident from the considerable amount of attention being devoted to bulk uranium dioxide alone as a fuel. It will also be apparent from the preceding discussion that the chief disadvantages of bulk UO_2 as a fuel lie in the related properties of low thermal conductivity and low thermal shock resistance. Materials both metallic and ceramic which have superior properties to bulk uranium dioxide in these respects are not difficult to find. As also pointed out previously, the production of high bulk density carbide is more difficult at present than high bulk density oxide so that the carbide could be more conveniently incorporated in disperse form in a matrix that will retain fission products.

The fuel dispersions considered will be for use in thermal reactors so that the dispersal medium will advantageously have a low neutron absorption cross-section. Such diluents are based primarily on the elements oxygen, carbon, beryllium, magnesium, silicon, aluminium, and zirconium; diluents which might be acceptable if special advantages were obtained could include niobium, titanium, nickel, iron, vanadium and molybdenum. Higher parasitic neutron absorption in the matrix material is, on general grounds, more tolerable for plutonium than for uranium fuels.

Compared with oxides, metals have high room temperature thermal conductivities which do not decrease rapidly with increasing temperatures and furthermore are not prone to failure under conditions of thermal stress. Using a metal dispersant the dispersed system can be fabricated much as a metal would be and the fuel core can be bonded to the can to give a fuel of high integrity.

With metallic matrices, from considerations of compatibility it seems that for dispersion fuel elements capable of operation at temperatures above 600°C, metals other than those of low neutron cross-section are required as matrices. Most of the metals of this second group are creep-resistant themselves, or form the basis of creep-resistant alloys. Iron, nickel, or molybdenum-based alloys would be suitable matrices for the fissionable dioxides but little data is available on their compatibility with the fissionable carbides. A good deal of experience has been obtained with UO_2/stainless steel dispersions showing that their irradiation behaviour is excellent. The high cross-section of the matrix makes this combination unattractive economically for thermal reactors, although the position would be more favourable with plutonium.

Graphite as matrix

For high temperature dispersion fuel elements an alternative to the use of the relatively high cross-section metals, iron, nickel and molybdenum, are graphite and the oxides and carbides of beryllium, aluminium, magnesium, silicon and zirconium.

Graphite possesses a number of properties highly desirable in a matrix material for a ceramic dispersion fuel. It has a low neutron cross-section, it does not melt but rather sublimes at a very high temperature (3200°C), retains its mechanical properties to well above 2000°C, and has a high room-temperature thermal conductivity which does not diminish as rapidly with rising temperature as does the conductivity of oxides. If the fissionable phase is a carbide no compatibility problems arise, for even if the monocarbides are used and react with the graphite to give the dicarbides, there is only a very minor volume change. If oxides are used then chemical reaction is possible.

Carbon will reduce uranium dioxide completely to the monocarbide at 1800°C with the evolution of carbon monoxide; below about 1200°C the reaction is very slow, the rates being influenced by the particle size of the oxide. Above 1000°C plutonium dioxide is reduced to the sesquioxide by graphite and above 1200°C formation of the monocarbide occurs. These figures indicate the upper temperature permissible in oxide/graphite fuels if carbon monoxide evolution is to be avoided.

Effect of temperature

Several factors will determine the maximum temperature attained within a fuel. The can/fuel gap will be important, and will be determined partly by the relative thermal expansions of can and core, and partly by the dimensional change of the fuel core under irradiation. Diminution of thermal conductivity as a result of irradiation damage must also raise centre fuel temperatures. Graphite has a much lower thermal expansion than any metallic canning material so that if the core is to remain in contact with the can, higher centre temperatures would be needed than if the coefficients of expansion were similar. Little information is available on the decrease in the thermal conductivity of graphite due to neutron or fission fragment bombardment above about 300°C. It is known that fission fragment damage is more serious than that due to fast neutrons and that the latter can reduce the conductivity by a factor of ten at room temperatures. This effect is known to diminish with increasing irradiation temperature up to 300°C due to annealing processes and would be expected to continue to diminish still further above 300°C. On neutron irradiation there is a volume increase in graphite which results from an increase in the *c* spacing which is under-compensated by a decrease of the *a* spacing. With increasing temperature (up to 300°C for low neutron doses) the degree of undercompensation diminishes i.e. the increase in volume diminishes. Extrapolation of these results to higher temperature would give a volume decrease upon irradiation.

Recent irradiation experiments upon

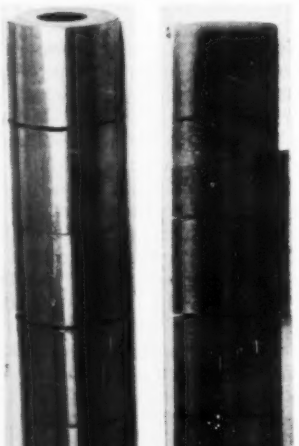
dispersions of fissionable ceramics in graphite have thrown further light on the problems of the release of fission product gases and on the dimensional stability of graphite under irradiation at higher temperatures. Dispersions of 50% by weight fully enriched UO_2 (1 micron) and UC_2 (20 microns) in graphite were irradiated to a burnup of 0·5% of the uranium atoms at 600°C (figure 6). The specimens were in the form of cylinders, the graphite density being about 1·5 g/cc. The graphite matrix exhibited a fairly strong preferred orientation with the basal planes tending to lie perpendicular to the cylinder axis; the thermal expansion along the cylinder axis was about 5 times the diametral expansion. After irradiation there were only minor dimensional changes: the diameters had decreased and the lengths had increased, the relative changes being such as to give on the average a slight decrease in volume. Appreciable proportions of the total fission product gases were released for both carbide and oxide dispersions as might be expected from the particle sizes employed, and from the permeability of the matrix.

Bearing these facts in mind, the most reliable fuel elements based on a graphite matrix would seem to contain fissionable carbides as the disperse phase, the monocarbides—being more stable in moist air — possibly being preferable to the dicarbides. An impermeable can is essential with such an element if fission products are to be contained.

Beryllia attractive

Beryllia and uranium dioxide are mutually insoluble in the solid state, so that a fuel element based on this combination of materials would be a true dispersion-type element. The thermal conductivity of beryllia is not quite as high as graphite at room-temperature and falls with increasing temperature in a manner common to most oxides. At 800°C, however, its conductivity is still greater than that of uranium metal. Its thermal shock resistance is high so that there is the possibility that cracking may not occur under irradiation, consequently relieving the can of some of the structural burden.

Data on the effects of irradiation and fission product damage upon the physical properties of beryllia at high temperature is meagre. Irradiation at room temperature to 10^{19}nvt has been reported to cause a dimensional change of the order of 1%, seriously affecting thermal conductivity and strength, but in other work a 0·3% expansion in the *c* spacing is quoted with no change in either the *a* spacing or the thermal conductivity. With beryllia, under fast neutron irradiation the (n, α) and (n, 2n) reactions will produce helium and tritium. The manner in which the beryllia is affected by this entrapped gas must be temperature sensitive. Fragmentation may occur at low temperatures, and at some elevated temperature the beryllia will



Hollow cylindrical specimen fuel elements of uranium carbide dispersed in graphite (left) were irradiated at 600°C to 0·5% burnup of uranium. Resulting appearance is shown at right (Fig 6)

become plastic and dimensional changes due to bubble formation will occur. This latter temperature will not be below 1000°C, and beryllia, having a hexagonal structure, might be expected to possess better creep strength in the polycrystalline form than the cubic oxides.

The only data available for fission product damage in beryllia is for 2 and 10 w/o dispersions of uranium dioxide in beryllia at unspecified irradiation temperatures. Linear dimensions increased by 1% and the thermal conductivity fell by a factor of six after a small burnup. Absence of any difference between the two concentrations was ascribed to the higher, but still unspecified, temperature of the specimens richer in uranium. This suggests that radiation damage of all types might be expected to diminish in magnitude with increased temperature of operation.

Alumina does not take urania into solid solution and vice versa so that a a stable dispersion can be formed. The alumina/plutonium dioxide system would probably be very similar. The thermal conductivity and thermal shock resistance of alumina is intermediate between those of magnesia and beryllia. Low temperature neutron irradiation causes no physical changes in polycrystalline material or single crystals other than in colour, but no data is available for fission product damage. Alumina based refractories can be most readily produced in impervious form by the addition of glass forming oxides, e.g. SiO_2, which ensure that there is a liquid phase present during sintering. The release of Xe-135 from dispersions of 100 micron UO_2 in such an impervious matrix has been found to be less than 0·030% at 800°C.

The carbides in general have higher room temperature thermal conductivities but, with the exception of silicon carbide, little is known of the variation of their thermal conductivity with temperature. Their thermal shock resistance is better than that of oxides. Little data is available on the irradiation behaviour of the carbides, again with the exception of silicon carbide.

Potential of SiC

The only carbide which appears worthy of consideration as a matrix is silicon carbide. Some six crystalline modifications of silicon carbide have been identified to date, but fortunately the beta form is stable up to about 2200°C. There are four commercially available types of silicon carbide. Until recently all silicon carbide materials were bonded with silicon, silicon nitride or silicates and the refractoriness, and mechanical properties at room and elevated temperatures, were to a large extent determined by the nature of these bonds. A self-bonded silicon carbide is now available and two methods of manufacture have been used. The details of a laboratory process only have been published and this involves hot compacting at 2200–2400°C. The commercial process of manufacture has not been disclosed but may involve cold-compacting and sintering of the elemental powders, at about 2000°C. It has been claimed that under optimum conditions material of 98% density and 98% purity can be produced, the chief impurities being silicon, carbide, aluminium and iron. Impermeable silicon carbide with various levels of impurities can therefore be produced. Irradiation data is again scarce but a dose of 10^{20} nvt at an unspecified temperature has induced 1% expansion in both the cubic and hexagonal forms of SiC, the damage annealing out at 1200°C. The main factor attaching to the use of silicon carbide which requires definition is the stable physical form in which uranium or plutonium would be present in an impermeable bonded or 'self-bonded' silicon carbide.

Temperature and reactivity

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Performance of power reactors is very sensitive to changes in temperature in both fuel and moderator. Here is a summary of the main effects, with special emphasis on GCRs

IN A REACTOR operating at steady power, neutron production in the fuel must exactly balance losses by absorption and leakage, i.e. the effective reproduction constant, k_{eff}, must be exactly unity. Thus the operation of a reactor is very sensitive to small changes which upset this balance. In a power reactor, reactivity changes* caused by changes in temperature are particularly important, since for example, a small change in power causes a change in reactor temperatures, which in turn cause a change in reactivity and hence a change in power. Thus the effect of temperature on reactivity provides a feedback mechanism: a negative temperature coefficient of reactivity enhances reactor stability, while a positive temperature coefficient provides a destabilizing effect.

In general, as a result of a change such as an alteration of power, different parts of a reactor change in temperature at different rates and by different amounts. In particular, in a heterogeneous thermal reactor, the temperature of the fuel changes more rapidly than that of the moderator due to its lower thermal capacity. It is therefore convenient to divide temperature effects into a fuel temperature, or 'prompt,' coefficient, and a moderator temperature, or 'delayed,' coefficient. The time constants associated with these coefficients depend on the reactor design.

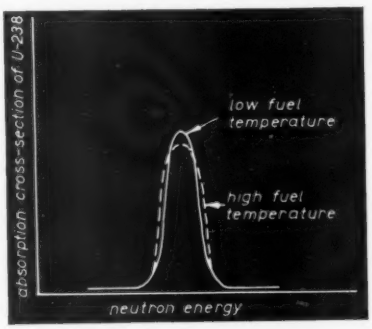
In a small reactor with considerable neutron leakage from the core temperature changes in the reflector may affect reactivity by altering neutron leakage, but this effect is negligible in a Calder-type reactor.

*The deviation of a reactor from the critical state is defined by the reactivity, ρ, which is the fraction by which k_{eff} differs from unity i.e. $\rho = (k_{eff}-1)/k_{eff}$. The change of ρ with temperature is known as the temperature coefficient of reactivity.

Fuel temperature coefficient

Changes in fuel temperature affect reactivity in two ways: by thermal expansion, and by changes in nuclear cross-sections (Doppler broadening).

1. *Thermal expansion.* This causes changes in fuel dimensions and density, but in a thermal reactor containing U-238 the effect on reactivity is negligible compared with that due to Doppler broadening effects. There may also be a reactivity effect associated with changes in coolant temperature due to thermal expansion of the coolant, but this effect is negligible in a reactor with a coolant which absorbs very few neutrons, such as carbon dioxide or helium.



Doppler broadening of resonance peaks in the fuel cross-section is caused by increased temperature (Fig 1)

2. *Doppler broadening effects.* An increase of fuel temperature causes increased thermal vibration of fuel atoms. Due to this thermal vibration, for neutrons of a given energy incident on the fuel there is a small spread in the relative velocity between the neutrons and the fuel atoms, and this causes resonance peaks in the fuel cross-section to be less sharp than if the atoms were stationary (figure 1). This phenomenon is known as Doppler broadening, by analogy with the Doppler effect in acoustics and spectrography. In a fuel containing a large amount of U-238, the effect of Doppler broadening in fissionable material is negligible compared with that in U-238. Wigner has shown that Doppler broadening causes resonance absorption in U-238 to increase if fuel temperature rises (*1*). This provides a negative fuel temperature coefficient of magnitude proportional to the resonance absorption in U-238 (i.e. approximately proportional to $(1-p)$ where p is the resonance escape probability for U-238). For a typical graphite/natural uranium reactor the fuel temperature coefficient is about $-2 \times 10^{-5}/°C$ i.e. the reactivity falls by about 0·1% if the fuel temperature rises by 50°C.

Moderator temperature coefficient

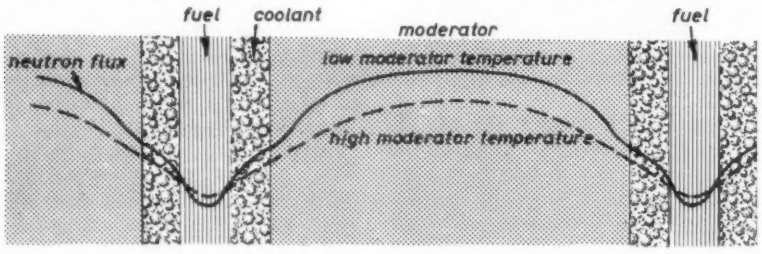
As with a change in fuel temperature, a change in moderator temperature affects reactivity both by thermal expansion effects and by changes in nuclear cross-sections.

1. *Thermal expansion.* This effect is generally negligible in a graphite moderated reactor due to the small coefficient of expansion for graphite. However, in most water moderated power reactors it provides the principal contribution to the temperature coefficient, and is usually large and negative. For example, in the American PWR reactor at Shippingport, the moderator coefficient is about $-50 \times 10^{-5}/°C$ at operating temperature (*2*).

2. *Change of neutron energy spectrum.* In a thermal reactor fast neutrons produced in fission are slowed down by collision with moderator atoms until they attain equilibrium with the thermal motion of the moderator

atoms. In the absence of neutron losses by absorption or leakage, the thermal neutron energy spectrum corresponds to the Maxwell-Boltzmann energy distribution of molecules in a perfect gas, the energy corresponding to the most probable velocity being kT, where T is the absolute temperature of the moderator and k is Boltzmann's constant. Thus a change in moderator temperature changes the spectrum of thermal neutrons, and this affects the relative rates of the various nuclear reactions taking place, since in general nuclear cross-sections are functions of energy.

In a thermal reactor, neutron production, absorption and leakage somewhat alter this distribution of energies. However, it is found that the energy spectrum can be fairly well represented by a Maxwell-Boltzmann distribution at low energies, together with a spectrum of neutrons slowing down which falls to zero at thermal energies. The temperature of the Maxwellian distribution is known as the neutron temperature, and it will in general be somewhat greater than the actual moderator temperature.



Increased moderator temperature causes neutrons to travel further than average, thus reducing the flux depression in the fuel (Fig 2)

Changes in cross-sections

For many materials, at low neutron energies the neutron scattering cross-section is approximately independent of neutron energy, while the cross-sections for radiative capture and fission vary approximately as $1/v$ i.e. inversely proportional to neutron velocity. If all capture and fission cross-sections varied as $1/v$, and if reactors were homogeneous and infinite, then a change in moderator temperature would change all absorption cross-sections in the same way, giving no change in relative absorption rates in the various materials and no reactivity change. In practice there will be a reactivity change, due to four effects:

1. Not all neutron capture and fission cross-sections vary as $1/v$, since the presence of neutron resonances at low energies causes deviation from the $1/v$ law in the thermal region for some isotopes. The fission cross-sections of U-235 fall off slightly more rapidly than $1/v$ at thermal energies, giving a small negative contribution to the moderator coefficient of a natural uranium graphite reactor. This arises because an increase of moderator temperature causes a decrease in U-235 fission, relative to absorption in U-238 and graphite. It should be noted that although there is considerable resonance absorption in U-238, the first resonance is at a sufficiently high energy for its capture cross-section to follow the $1/v$ law at thermal energies. In a typical natural uranium/graphite reactor, this effect in U-235 contributes about $-5 \times 10^{-5}/°C$ to the moderator coefficient. The presence of plutonium in the fuel gives a positive contribution which will be discussed later.

2. An increase of average neutron energy causes a decrease in neutron absorption cross-sections causing neutrons to travel further before absorption. This increases losses of thermal neutrons by leakage from the core boundaries, giving a negative contribution to the moderator coefficient. The effect will be large in a small reactor where there are large leakage losses, but in a reactor such as the Calder Hall type the contribution is only about $-1 \times 10^{-5}/°C$.

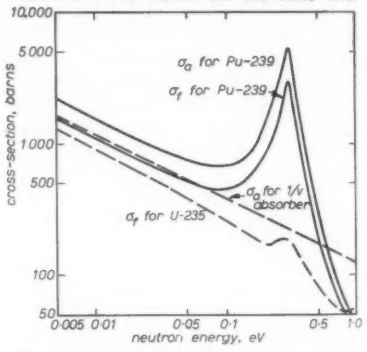
3. In a heterogeneous reactor, since most of the absorption occurs in the fuel there will be a depression of neutron flux there. An increase of moderator temperature will cause neutrons to travel further on the average, before absorption, reducing the flux depression (figure 2). This causes the mean neutron flux in the moderator, relative to that in the fuel, to decrease, thus reducing relative thermal neutron losses in moderator absorption and leakage and giving a positive contribution to the moderator coefficient. In a Calder-type reactor this gives a contribution of about $+2 \times 10^{-5}/°C$ for unirradiated fuel, although it could be greater in a reactor with a larger flux depression in the fuel.

4. The effectiveness of control rods increases with moderator temperature. If the control rods and fuel are $1/v$ absorbers, an increase of moderator temperature will reduce the absorption cross-sections of fuel and control rod material atoms in the same way. However, since the control rod is a heavily absorbing material which absorbs most of the thermal neutrons incident upon it, a decrease in the absorption cross-section of each atom will not appreciably alter the total thermal neutron absorption in the rod. Thus the absorption of neutrons in the rod, relative to that in the fuel, will increase, giving a negative contribution to the moderator coefficient of a reactor core with control rods inserted. This effect has been observed at Calder Hall, where an increase of about 200°C in moderator temperature increased the control rod effectiveness by about 12% in an unirradiated reactor (*3*).

All these effects depend on both moderator temperature and fuel composition: in particular they will change with irradiation due to changes in fuel isotopic content.

Effect of irradiation

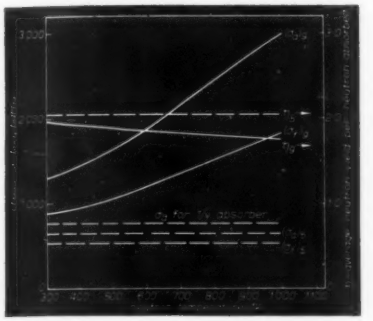
In a natural or low enrichment uranium reactor, irradiation causes U-235 to be burnt and replaced by Pu-239, formed by neutron capture in U-238. This has little effect on the fuel temperature coefficient, which is almost entirely contributed by U-238 since the fractional burnup of U-238 is negligibly small. However, the build-up of plutonium will have a very large effect on the moderator temperature coefficient, since the fission and radiative capture cross-sections of Pu-239 depart very considerably from the $1/v$ law at thermal energies due to the presence of a resonance at 0·3 eV (figure 3). An increase of moderator temperature causes a greater fraction of neutrons to be absorbed in this resonance giving an increase in reactivity.



Fission and absorption cross-sections for Pu-239 as a function of energy (Fig 3)

The contribution of Pu-239 to the moderator coefficient of a reactor can

be determined by finding the variation with moderator temperature of the Pu-239 cross-sections averaged over the neutron spectrum. It is convenient to carry out this averaging in a manner proposed by Westcott (*4*) in which the average value is calculated relative to that for a $1/v$ absorber in the same spectrum, so that the Westcott average cross-section for a $1/v$ absorber is the same in all neutron spectra. Values of Westcott cross-sections have been calculated for Pu-239 and other isotopes, in a range of spectra (*5*, *6*). The variation of the Westcott fission cross-section of Pu-239 in



Variation with neutron temperature of Westcott average cross-section of Pu-239 for typical thermal reactor spectrum (Fig 4)

a typical thermal reactor spectrum with neutron temperature is shown in figure 4. Also shown is the Westcott absorption cross-section, i.e. fission plus radiative capture, and the average neutron yield per neutron absorbed ($\eta \propto \sigma_f/\sigma_a$). Similar curves are given for U-235. These quantities would be constant for a $1/v$ absorber, and it is clear therefore that competition between neutron absorption in Pu-239 and thermal absorption in U-238, graphite, etc, will provide a large positive contribution to the moderator coefficient, although this will be partly offset by the fall of η for Pu-239 with temperature. Thus the moderator coefficient becomes positive as plutonium builds up in the fuel.

Effect of the fuel cycle

In general fuel elements in a reactor will be at a variety of different irradiation levels, and surrounded by moderator at a variety of different temperatures. Thus the moderator temperature coefficient of reactivity is a function of position, and the overall coefficient must be found by suitably averaging the contribution from each point in the reactor. For a large reactor, application of the statistical weight theorem (*7*) for summing reactivity effects over a reactor shows that the overall moderator temperature coefficient will be approximately

$$\overline{\alpha_M} = \int_{\text{core}} \alpha_M \, \phi^2 \, dV \Big/ \int_{\text{core}} \phi^2 \, dV$$

where α_M is the moderator temperature coefficient for a region with average thermal flux ϕ that is the value of the moderator temperature coefficient for the reactor if all fuel had the same average composition as the region. $\overline{\alpha_M}$ will depend on the fuel cycle adopted; this can be demonstrated by considering two extreme fuel cycles.

First, consider a bulk discharge cycle in which all fuel in the reactor is replaced at the same time. Then, for example, in a Calder Hall reactor at an average irradiation level of 1000 MWd/t, fuel at the centre will exceed 2000 MWd/t. This high irradiation fuel will have a large value both of α_M, and ϕ^2, and it will consequently make a disproportionately large contribution to α_M. Calculation shows that the moderator coefficient would be approximately the same as that for a reactor with all fuel at the same irradiation level of about 1500 MWd/t.

In contrast, consider a graded cycle in which fuel is replaced more or less continuously so that it all reaches the same irradiation level before discharge, fuel in low flux positions being left in the reactor longer than that in high flux regions. Then, for example, if the discharge level is 3000 MWd/t in any region of the reactor there will be fuel of all irradiation levels from approximately 0 to 3000 MWd/t. Thus the overall temperature coefficient of the reactor will roughly correspond to that for a reactor with all fuel at an irradiation of about 1500 MWd/t.

It is apparent, therefore, that a graded fuel cycle will give much lower moderator coefficients than a bulk discharge cycle, for the same average irradiation level for discharged fuel. The first Central Electricity Generating Board reactors are designed to operate on a graded cycle, although in practice there will be some spread in maximum fuel irradiations. It is expected that for irradiation to about 3000 MWd/t, a moderator temperature coefficient of up to about $+15 \times 10^{-5}/°C$ will be experienced (*8*).

Experimental measurements

Prediction of moderator temperature coefficients demands both accurate measurements of fundamental cross-section data, and a detailed knowledge of the neutron spectrum in the fuel at low energies and its variation with moderator temperature. In particular, detailed knowledge is needed of the neutron spectrum in the region of the 0·3 eV resonance for Pu-239. Unfortunately in this region neutron thermalization is taking place, and consequently spectrum predictions are difficult, requiring detailed data on neutron scattering by moderator atoms. Furthermore the spectrum is perturbed by the presence of Pu-239. Thus, at present, reliable predictions of neutron spectra must be based on direct measurements in reactor lattices (*9*).

Direct measurements of temperature coefficients provide an essential check of methods and data for calculations. An extensive series of measurements has been made on the Calder Hall reactors by Leslie (*3*). It was found that, under operating conditions, the uranium temperature coefficient was $-2{\cdot}4 \times 10^{-5}/°C$, and the moderator coefficient increased from $-2{\cdot}5 \times 10^{-5}/°C$ for an unirradiated charge to $+4{\cdot}7 \times 10^{-5}/°C$ at an average irradiation level of 450 MWd/t (for bulk discharge operation). These results and measurements at lower temperatures agree well with predictions.

Positive coefficient at Calder

The presence of a positive moderator coefficient will affect the response of a Calder-type reactor to changes in power, coolant flow, etc. However, the first effect of a change such as an increase of power will be an increase of fuel temperature, which, because of the negative fuel coefficient, will lead to a reduction in reactivity and hence of power. The moderator temperature will rise more slowly, but with a large positive moderator coefficient this may eventually cause a net increase of reactivity, and amplify the power disturbance. For example, for a typical CEGB reactor with a moderator coefficient of $+15 \times 10^{-5}/°C$, a power disturbance will increase with a doubling time of about 2 minutes. Thus if in a reactor operating at a steady power of 500 MW the power increased to 501 MW, it would increase to about 502 MW after 2 minutes, to about 504 MW after 4 minutes, and so on (*8*). Such changes are slow compared with the time taken to detect the change, and for an operator, or an automatic control system, to readjust the power level.

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ENGINEERING AT OLYMPIA

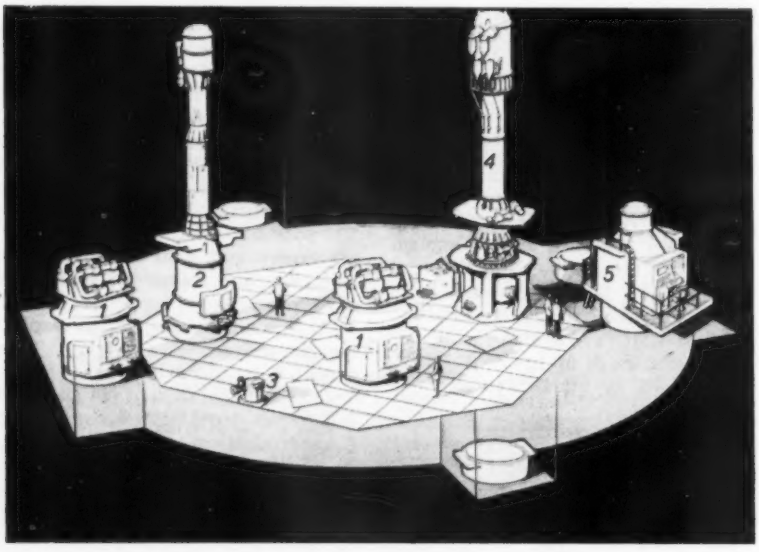
Nuclear highlights at this year's show

Opened on April 16 by Sir Edward W. Thompson, M.A., J.P., President of the British Engineers' Association, the Engineering, Marine, Welding and Nuclear Energy Exhibition will run until April 30

POWER PRODUCTION

English Electric and Babcock & Wilcox are showing their work on the Hinkley Point project, the world's first 500 MW atomic power station, and its compact design enables it to occupy no more ground space than required for the current 300 MW stations. Babcock & Wilcox's widening activities through technical collaboration with The Babcock & Wilcox Company of America are shown and include progress in nuclear ship propulsion, directed at pressurized-water reactors similar to the unit being incorporated in NS *Savannah*, the first American merchant vessel.

By far one of the most interesting exhibits is in the nuclear power plant section where for the first time John Thompson's fuelling equipment for the Berkeley Nuclear Power Station is publicly shown. This consists of a 40 ft high fuel chute machine, control rod actuator servicing machine (40 ft high), charge/discharge machine, visual observation and removal equipment, flux scanning winch and rotatable magazine, all of which are exhibited by means of models in their correct relation to the reactor face at Berkeley. The top of the fuel chute is a pressure vessel containing the upper portion of a three-channel rotatable magazine and winding gear with a main and emergency cables supporting the lifting grab. An external differential gearbox maintains a 10 : 1 load ratio between the main and emergency cables. The grab and latch drives pass through pressure-sealed glands from the top section; these drives connect or disconnect the grab and position latches in the magazine channel used to support and clear the various fuel chutes. Before the fuel chute is connected to the reactor vessel for operating it is cleared of air and filled with CO_2.



HOW THE FUELLING EQUIPMENT WILL LOOK AT BERKELEY—the John Thompson's units located on the reactor face
1. Charge/discharge machine; 2. Fuel chute machine; 3. Flux scanning winch; 4. Control rod actuator servicing machine; 5. Visual observation and removal equipment

An integral part of the fuel charge/discharge machine is a 4 ft dia magazine which enables a full load sufficient for one reactor fuel channel to be carried in the machine. This magazine is automatically indexed and provides either thirteen fuel elements or empty pockets for exhausted elements for one reactor vessel fuel channel. To ensure absolute accuracy in positioning a Geneva mechanism is used to index the magazine. Each of the twenty pockets are fitted with a stirrup-shaped latch on which the fuel elements can rest and only when there is no weight on the latch and its pocket is in line with the grab can the latch be freed to allow a clear passage downwards. Exhausted fuel elements are kept cool while in the magazine, and indicating switches show the contents of each pocket.

On the top of the fuel charge/discharge machine is a differential gearbox driving the discriminator which shows at all times the position of the grab inside the chute machine and the length of stretch of the main cable; the figure of stretch enables a reliable estimate of life of the cable to be made.

On the International Combustion stand the Atomic Power Construction Co show their activities in the nuclear power field with special reference to the welding and forming involved in pressure and heat exchanger equipment.

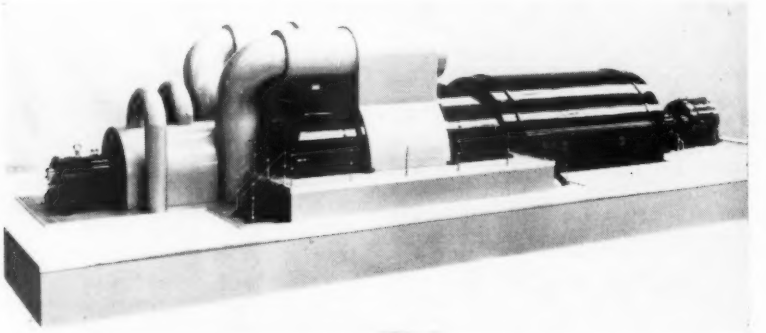
To overcome the comparatively poor steam conditions encountered in a nuclear power station C. A. Parsons & Co show a model of a 100 MW turbo-

generator using a dual pressure cycle. In this cycle a quantity of steam is generated at a low pressure and the remainder at a much higher pressure. The steam from the high pressure range expands through the h.p. turbine down to a mixing chamber into which steam from the l.p. range is injected and the mixed steam expands through the l.p. turbine to the condenser. Due to the low temperature there is a large volume flow of steam for a given output which results in a somewhat larger exhaust area than that for a similar sized machine using a modern conventional steam-generating plant. The generator is of the normal hydrogen-cooled design using a direct gas-cooled rotor.

A model of a reactor suitable for the dual pressure steam cycle generating plant is also exhibited and is of the CO_2-cooled, graphite-moderated type with overhead fuelling which enables fuel changes to be made while the plant is operating.

actors such as DIDO and PLUTO; the master and slave coarse control gearbox, the fine control gearbox and the safety gearbox for such systems are exhibited for the first time in the UK. A new piece of equipment for use in these reactors is the Hobson-AERE honeycomb isotope unit—this enables up to seventy samples to be treated at one loading and different elements, requiring varying irradiation periods, can be included. An indexing system provides for remote loading and ejection of any selected sample without disturbing any of the others and CO_2 is used to transfer the sample to and from the honeycomb assembly located within the reactor. Hobsons are also showing the American CRL Model 7 Master/Slave Manipulator which they are now manufacturing under licence in the UK.

After an absence of eight years the Sperry Gyroscope Co has returned to this exhibition and their Industrial Division activities are shown by a fine position indicator for control rods and a complete reactor control rod winding mechanism design. This division is responsible for complete process controls.



USING A DUAL PRESSURE CYCLE TO IMPROVE EFFICIENCY—the Parsons 100 MW turbogenerator employing steam conditions most suitable for a nuclear generating station

CONTROL MECHANISMS

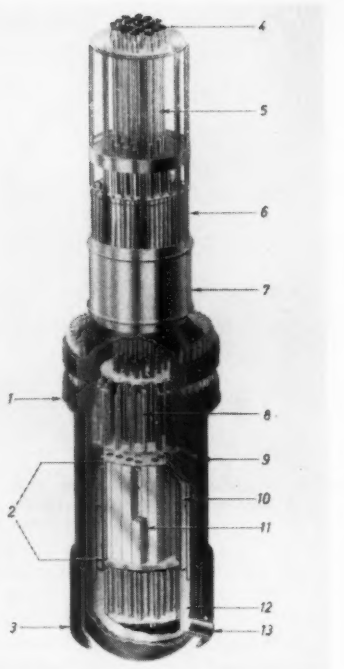
A control-rod head as being supplied to the Bradwell nuclear power station is A. Reyrolle & Co's central feature. The raising and lowering equipment is driven from a synchronous motor in the head and as extremely low rotational speeds are necessary, special low-frequency supplies are required. These are provided from a low-frequency generator set, also on show, with frequencies variable between zero and about one-half cycle per second in either direction.

An associated piece of equipment is the Reyrolle gas-sampling selector valve for continuous automatic selection of the gases circulating in a number of fuel channels. This passes them to a monitoring system which indicates the radioactivity of the samples on chart recorders.

In H. M. Hobson Ltd we have a company which has devoted its activities to specialized fields of nuclear engineering. For some years this organization has developed control systems for heavy water-moderated-and-cooled thermal re-

GAS CIRCULATION

With gas temperatures and pressures increasing to meet present and near future requirements considerable work has been carried out on the design and manufacture of gas circulators. The NFB gas bearing circulator is the first product from the Ruston & Hornsby Group's Nuclear Engineering Department and is

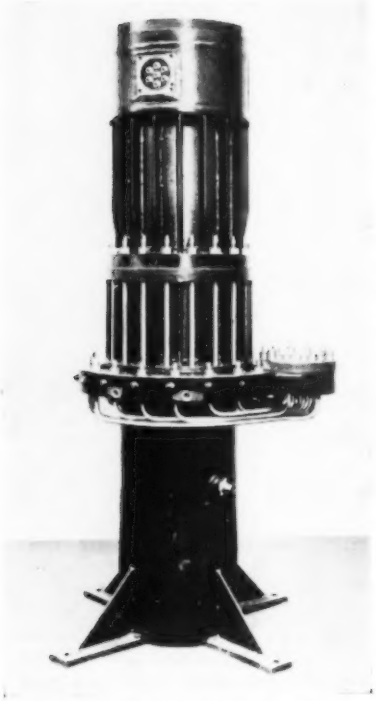


BASIS OF MARINE REACTOR ENVISAGED BY BABCOCK & WILCOX—the PWR for the NS 'Savannah'
1. Pressure vessel; 2. Core; 3. Support skirt; 4. Control rod drives; 5. Scram cylinders; 6. Lead screw drive; 7. Gland seals; 8. Control rods; 9. Water outlet; 10. Thermal shield; 11. Fuel elements; 12. Flow baffle; 13. Water inlet

suitable for circulating gas at high temperature and pressure without leakage; its rotating assembly is carried on bearings which use the pumped carbon dioxide, helium, air or other gas as the bearing fluid.

To meet these requirements several aircraft engineering companies have applied their high speed and close inspection techniques normal in aeronautical engineering to gas bearings, compressors, pumps and rotating seals; these are for applications where contamination due to leakage of lubricant cannot be tolerated and once the plant is installed is inaccessible. The Bristol-Siddeley group now introduce a range of gas bearing compressors and vertical pumps designed for pressures up to 1700 psi and a high temperature range of 250–500°C. Another interesting exhibit from this group is

PRODUCING ISOTOPES ON A COMMERCIAL BASIS—the Hobson-AERE Honeycomb isotope unit enables up to seventy samples with varying irradiation times to be treated at one loading



SYNCHRONOUS MOTOR DRIVEN CONTROL ROD HEAD. A Reyrolle unit as is being manufactured for the Bradwell nuclear power station

the high precision hardened ball and recirculating lead screw unit made under licence from the Beaver Co of America. This, with its very high degree of accuracy (0·0005 in. per ft), has many potential uses in the nuclear field.

Napiers, one of the English Electric Group, have developed two gas seals for use in CO_2 circulators, one lubricated by gas and one by oil, and a combined gas seal and thrust bearing. The combination unit is for power station service and in this application the sealed gas pressure may be as high as 100 psi, the rotational speed up to 10,000 rpm and with a thrust load of 5000 lb.

Another aircraft manufacturer at this show is Sir W. G. Armstrong Whitworth Aircraft Ltd and amongst the products shown from their general engineering activities are fuel cans of the Calder Hall type for the AEA. The production machinery for the cans was specially made by the company's process development department.

DEVELOPING NEW MATERIALS

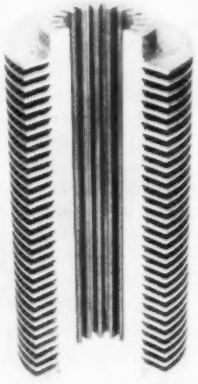
One of the major problems in all reactor projects is the efficient transfer of heat from a radioactive circuit to a 'safe' circuit whether it be for power production or cooling purposes. To obtain the maximum efficiency several tube manufacturers have developed special extended surface tubing. This type of material is of two basic types, both of which have external horizontal finning welded to the body of seamless tubing—one has a smooth bore and the other has internally forged vertical ribs, these giving increased contact area with minimum interference to the primary flow. In all cases the pitch and dimensions of the fins and ribs can be varied to suit any particular design requirements. A wide range of different forms are shown on the stands of Tubes Ltd and Accles & Pollock Ltd. In addition, tubing and fittings used on nuclear engineering projects are shown amongst others by Talbot-Stead Tube Co and Stewarts & Lloyds, the latter having a control rod standpipe for the Hunterston nuclear power station as their principal exhibit.

A very wide range of components from fuel cans to pipework for nuclear equipment is made from aluminium. The Northern Aluminium Co is exhibiting a selection of these components together with examples of Noral aluminium fabrication typical of those now being made for the various nuclear power plant projects.

With more and more emphasis being put on high temperature operation a number of non-metallic materials are increasing in importance. Lodge Plugs have, over the years, developed suitable materials for their own products as a result of which they are now able to offer an impervious alumina ware for industrial purposes. This ceramic material known as Sintox has good electrical and mechanical properties at high temperatures and is resistant to chemical attack. Of particular value for nuclear applications is the FFI grade which has the additional feature of low neutron capture cross section, compatible with most materials employed in the internal construction of reactors.

MAKING UP PIPE CIRCUITS

As in all process engineering, valves, pipe-fittings and accessories form a major part of the equipment to be installed. With the introduction of nuclear engineering a new series of items have been designed which, by virtue of their materials of construction, are acceptable and do in fact represent a combination of a number of British and American general and petroleum standards. British Arca Regulators have introduced a Double Beat Diaphragm Valve which has already been tested in a nuclear power station; CAV are exhibiting electro-pneumatic valve units for servomechanisms and Blakeborough's are showing

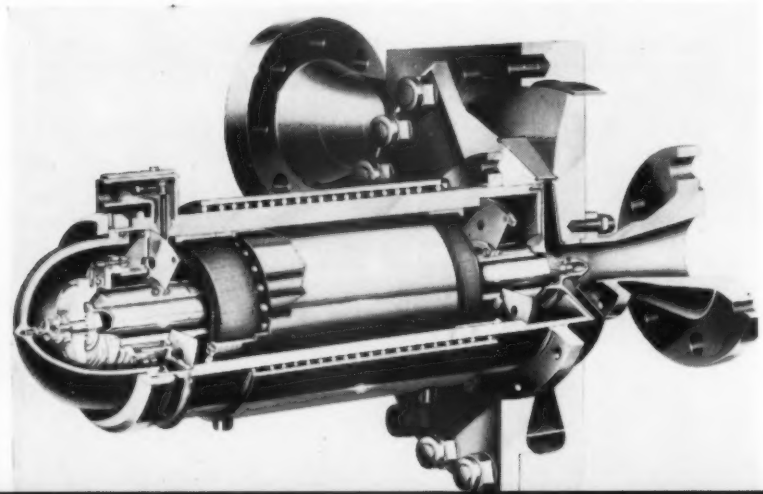


THE MAXIMUM HEAT TRANSFER area is obtained with minimum flow restriction—one of Tubes Ltd extended finned tubes

the 'giant' valve of the show—a 60 in. bore motor operated butterfly valve for main gas duct service of power producing reactors. Other types of Blakeborough valves include bellows-sealed gate and globe valves for radioactive gas conditions on secondary CO_2 circuits.

A very comprehensive range of conventional valves in various grades of ferrous and non-ferrous materials are made by Newman Hender and are incorporated in a number of UK reactors. Similarly Saunders Valves have wide applications in the nuclear field and their diaphragm valves have been used extensively in applications ranging from the mining of uranium, main reactor lines to process lines dealing with reprocessing spent fuel. Exhibits include stainless

DESIGNED FOR HIGH PRESSURES AND TEMPERATURES—the water or air-cooled Bristol Siddeley gas bearing compressor for nuclear applications



steel valves used on the heavy water lines for the UK and overseas MTRs.

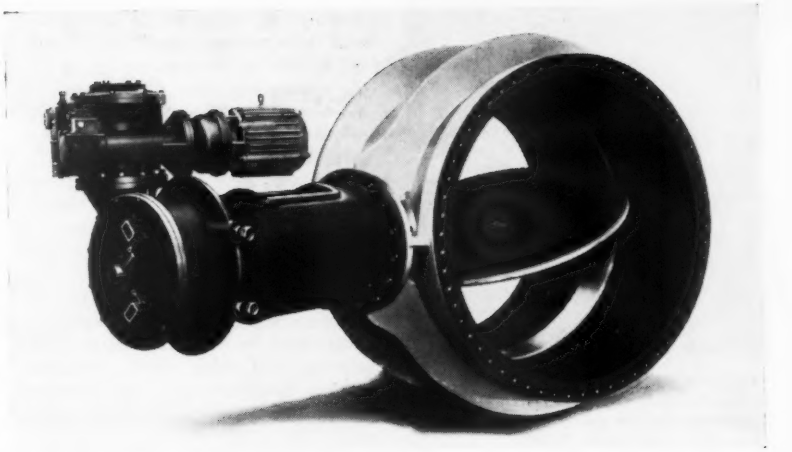
Other new pipe fittings include Copes Pressure Compensating Regulators which have made direct acting modulating control possible for the first time on nuclear boilers and of which over a hundred are being supplied for the present nuclear station programme. Vokes Genspring Ltd have introduced by way of a model their latest type M6 support hangers which will be used in supporting the CO_2 cooling circuit at Hinkley Point. It is capable of supporting a load of 90,000 lb over a vertical movement of 4 in. travel and are capable of accommodating vertical travels of up to 12 in. with reduced loading. Industrial Hydraulics introduce for the first time a new pipe coupling known as the KeelaTite—these have been developed to meet the requirements of high pressure hydraulic installations and may be used with any of the usual metal tubes.

Flexible hoses and self-sealing couplings have several important applications in nuclear work, especially for the occasional transferring or withdrawal of active liquids and gases. Automotive Products associate the new Lockheed Precision Engineering company are showing examples of their Avery couplings and hoses, several sizes of which have been supplied to reactor establishments at home and abroad. In certain installations it is necessary to utilize stainless steel and Power Auxiliaries have developed their 'Plessiflex' seamless flexible hose to meet this requirement.

Fabrications in the 'new' metals such as zirconium, titanium, niobium and vanadium are displayed by the ICI Metals Division, who with Marston Excelsior Ltd are showing components ranging from fuel cans and burst cartridge detection gear to extended surface boiler tubes and heat exchangers. Similar high temperature and pressure fabrication work, but in various forms of steels, is exhibited by the Aiton Company.

DEMANDS FOR GOOD SEALING

Due to the active and toxic dangers associated with reactor operation particular attention has to be paid to sealing of components in pipelines and machinery and synthetic rubbers have been applied in increasing quantities over the past year. For most normal purposes neoprene-based materials are employed but with the steady increase in operating temperatures, seals and packings employing silicone-based materials are coming into service. The Beldam Asbestos Co have packings and sealings which are effective against corrosive liquids and are suitable for temperatures up to 300°C. Precision Rubbers Ltd have recently developed a range of high temperature grades of their Prescolastik silicone rubber and Viton for fuel and acid resistance up to 300°C. Showing for the first time, Dowty Seals Ltd are exhibiting their new Selon range of nylon sealing washers, O-rings, U-rings, flange seals and associated precision mouldings in synthetic and silicone rubbers and PTFE, certain of which are designed for high temperature and irradiated conditions.



STRESSED-SEAL type 60 in. bore Blakeborough motor-operated butterfly valve as is used on main gas ducts. Tight sealing is maintained under substantial pressures and thermal shock conditions

Parallel with the problems of successful sealing for nuclear engineering equipment is the necessity for lubricating machinery which is either handling active materials or operating in an active area. Shell-Mex and BP have developed a series of irradiation-resisting lubricants and they are exhibiting the results of irradiation tests on Shell APL grades used in the nuclear power industry. Wakefield-Dick have also developed a range of radiation-resistant lubricants and are providing an advisory service on lubrication techniques at the exhibition.

PUMPS AND COMPRESSORS

The very extensive range of pumps and compressors on show at this year's exhibition covering all industrial and process requirements include a number of units which have special nuclear applications. In any nuclear power or research project many pumps and compressors of conventional design are employed although special materials may be incorporated constructionally.

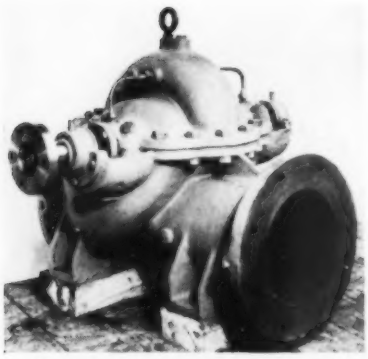
To achieve the necessary efficiency in service it is frequently necessary to carry out considerable trial work; on W. H. Allen Sons & Co's stand is a 10/10 in. 2,000 gallons/minute centrifugal pump which was used to verify the design of the circulating pumps for Chapelcross. Four 48/48 in. 50,000 gallons/minute vertical pumps were supplied, each of which is driven by a 1,225 h.p. Laurence, Scott & Electromotors water-cooled, totally-enclosed vertical electric motors.

From Germany are the KSB's glandless circulating pumps which have been designed for pressures of up to 3,600 psi and temperatures up to 750°F. Pumps of this type are being tested for a number of MTR reactor projects. Special AMAG valves for atomic power plants are also shown; these are either magnetically or pneumatically operated, have leak detection connexion points and as a special safety feature have a bellows-type gland backed by a normal gland.

Hamworthy Engineering are making pumps for a wide range of duties which are of the centrifugal, screw, gear and turbine types; included is a range of hydraulic pumps, motors and valves suitable for control purposes. Specializing in pumps for chemical processing, LaBour's have introduced the SZ, MSZ and DSZ series of pumps for nuclear processing purposes. These are available in various materials of construction, such as steel, bronze and aluminium, to match the particular fluids or slurries to be handled.

Utilizing the sliding-shoe principle Megators have introduced Unit Pressure Sets. These provide in one working unit main and standby pumps which enable simple yet effective changeover to be carried out at all times.

As in the case of pumps, many different forms of compressors are being shown which may be incorporated in nuclear installations. Sir George Godfrey & Partners' positive displacement Roots-type industrial blowers, because of their ability to deliver oil-free gases, have been applied to a number of reactor projects. For circulation and filtration of air within a reactor building a number of fans and exhausters have been used—Keith Blackman Ltd are prominent in this field and their 70 in. type AR impeller with backward bladed aerofoil section blades providing efficiencies up



10/10 IN. ALLEN PROTOTYPE PUMP used fo design tests of larger similar types for nuclear power station circulating-water duties

to 90% is representative of the company's equipment for handling large air volumes against moderately high resistance.

The B. A. Holland Engineering Co make an interesting range of rotary compressors—the Holland/SLM units. Their exhibits include examples of one type working both as a compressor and as a vacuum pump. Four 65 b.h.p. Holland/SLM rotary exhausters are being supplied to Metropolitan-Vickers for installation at the Berkeley power station and with a 95% vacuum the suction capacity of each of them is 1,120 cu ft per minute.

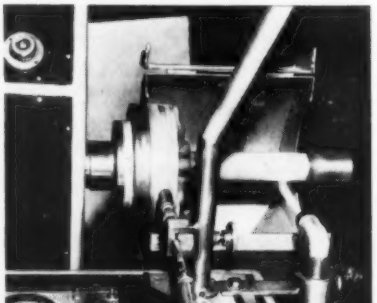
Conventional air and gas compressors are well represented by the Reavell Company and Williams & James (Engineers) Ltd and both these companies are making units for various nuclear applications in the UK. Williams & James also produce a range of ancillary equipment for controlling and cleaning compressed air. This equipment is in use on the instrument air-lines of research reactors at Harwell and Dounreay.

WELDING EQUIPMENT

Due to the special requirements associated with nuclear engineering manufacturers of welding equipment and associated inspection items have had to introduce an extensive range of new items and techniques. The problems to be solved were threefold; welding stainless steel, aluminium and the 'new' metals, zirconium, niobium, beryllium and titanium; welding on site very heavy plates for large pressure vessel; and meeting very stringent inspection requirements including the wide use of radiography.

A great deal of work is being done to perfect welding techniques for the wide range of metals. Murex Welding Processes have introduced two general purpose fluxes and the associated wires—Muraflux A is for the welding of mild steel by the submerged arc process and Muraflux SI for stabilized and unstabilized 18/8 stainless steels and Murawire W1 or W2, or Murawire SW1 or 2 are the appropriate filler wires; these combinations give welds of good mechanical properties and radiography of high standards can be achieved.

Quasi-Arc have designed Ferron 3 specifically for the nuclear energy industry; this combines ease of application with the deposition of weld metal having exceptionally good low-temperature impact properties. Lincoln Electric have produced a complete range of fused and unfused fluxes for mild steel, stainless iron, stainless and alloy steels. Associated welding equipment has been developed in parallel not only to take advantage of



METAL SRAYING AND FUSING to base metal is carried out in one operation by the Deloro Stellite hard-facing machine

the new materials available but to accelerate welding times without any reduction in the standard of workmanship.

Atomic hydrogen welding equipment is shown by Metrovick and a number of ingenious fabrication machines are exhibited. Manipulators, especially for large vessel fabrication, have received special attention over the past year and Yates Plant Ltd are producing rotators of up to 75 tons capacity and manipulators capable of handling 10-ton work pieces. Other interesting welding positioners have been developed by F. Bode & Son Ltd, including units with turntables incorporating infinitely variable speed. Fabrication tools used in connexion with the various welding techniques have been developed and considerable progress has been achieved by Hancock & Co (Engineers) Ltd. Their 'Hancoline' automatic electronic oxygen profiling machine dispenses with the conventional template. All that is required is a simple pencil line drawing of the workpiece of approximately finished size. The machine automatically compensates for width of cut and thus in the same way provides for instant correction of small overall dimensional inaccuracies in profiles. Another solution to the problem of simplifying profile-cutting is achieved by the British Oxygen Co in a unit which utilizes computer-control.

To ensure that the completed welding is satisfactory for nuclear applications industrial radiography is now widely used. Marconi Instruments have introduced a new 300 kV apparatus and is suitable for the examination of heavy castings and seam welds in steel plates up to four inches thick. To comply with site inspection requirements a number of small portable and medium transportable units are also shown.

SURFACE SPRAYING

A secondary metallic coating applied to the parent metal of moving parts is of assistance when complying with either arduous working conditions or extended service periods. For nuclear applications where frequent lubrication is not possible and servicing presents difficulties these techniques are employed. Deloro Stellite Ltd introduce a prototype unit designed to mechanize the Spray-Fuse 'Stellite' hardfacing process. This method of protecting components against wear, heat and corrosion, consists of an initial deposition of Stellite powder by metal spray, followed by fusing to the base metal. Metallization equipment includes a new unit for the flame spraying of powdered materials: not only metals can be used but non-metallic materials such as nylon, alumina, and zirconia may be sprayed. Metallizing Equipment Co have developed an electronically controlled metallizing machine, as well as equipment for hard-facing coatings of either a metallic or ceramic form.

Conventional metal plating techniques have also been developed to provide hard corrosion-resisting sufaces and specially cleaned and smoothed surfaces. Albright & Wilson have, over the past year, greatly widened the use of their Kanigen plating system and it is now being employed to finish components such as the operating jaws of master/slave manipulators. Kanigen is also used extensively to combat corrosion caused by uranium hexafluoride and it is recognized by the AEA as a satisfactory method of combating ion contamination. Electrolytes based on phosphoric acid have been used more and more during the past year and exhibits show the results which have been obtained with the new Phosbrite 501.

Among the conventional engineering equipment there are many items which may be used in conjunction with nuclear engineering and installations; these include various heat exchangers, machine tools, space-heaters, water treatment plant, dust and fume extraction equipment and even industrial cleaners.

Last month in this series W. R. Loosemore showed how to determine the expected response of a detector. Now A. L. Gray considers how the response to unwanted radiation influences detector choice

RADIATION DETECTORS

3—their operating limitations

by A. L. GRAY, BSc
Plessey Nucleonics Ltd

ANY PARTICULAR DETECTOR may only be expected to respond to incident radiation within certain limits determined by a number of factors. A pulse counter, for example, only shows a linearly increasing output pulse rate for an increasing radiation level so long as the interval between pulses does not approach the resolving time of the counter. Similarly an ionization chamber response is only linear so long as it is used in radiation fluxes below those in which the ionization density is too great for saturation.

All types of detector are limited by their response to unwanted radiation and the choice of detector is often dictated by the need for some discrimination against radiation other than that to be measured. The lower limit of sensitivity is set by the background level which is ultimately due to the activity of the structural material of the counter and to the effect of cosmic radiation. Finally the detector chosen must be of sufficient sensitivity to provide from the lowest level to be measured a statistical error small enough to be within the limits of accuracy required.

The purpose of this article is therefore to consider the influence of these factors on the choice of a detector and the limits within which corrections may be applied for their effects.

Detector resolution

The resolution of a radiation detector may be defined as the shortest time interval between successive events for which discrete output pulses are produced. The term loses its meaning for detectors used in the d.c. mode since these do not distinguish the occurrence of individual ionizing events, but for all pulse detectors it determines the upper limit of count rate at which the detector may be used, however fast any associated equipment will operate. This in turn limits the effective range of measurement since the practical lower limit of count rate is determined by statistical considerations which are similar for all pulse counters.

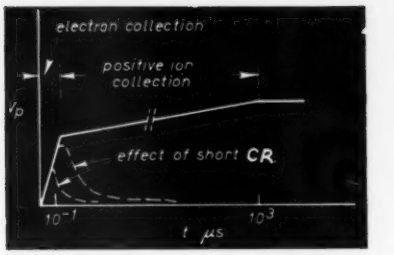
The effect of the finite resolution of a counter is that at high counting rates a proportion of the counts are lost since they occur during a period in which they are not separately recorded. If n_t is the true counting rate and n_o the observed rate the relation between them is

$$n_o = n_t \exp(-n_t \tau)$$

where τ is the resolving time.

The resolving time varies greatly between the different mechanisms of detection, values anywhere between milliseconds and millimicroseconds being common, the corresponding maximum possible count rates lying between 10^2 cps and 10^7 cps.

As has already been mentioned the use of ionization chambers as pulse counters is limited to a few special cases, of which the measurement of particle energy in a gridded chamber and the use of the electron collection fission chamber for neutron detection are examples. The time required for the complete collection of the ions produced between the electrodes of an ionization chamber is usually of the order of several milliseconds since the velocities attained by the heavy positive ions with practical collecting fields are relatively small. Any ionizing event occurring before the collection of the ions produced by the preceding event is not counted separately,

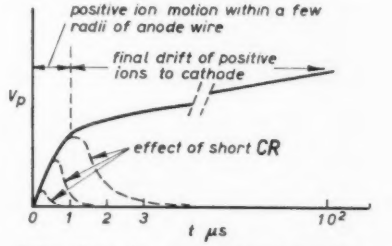


Pulse shape in an ionization chamber shows the effect of the differentiating time in the amplifier (Fig 1)

and when the chamber is operated so that the whole of the ionization must be collected each time, the maximum count rate is limited to a few hundred counts per second. If however a short time constant is used in an early stage of the associated pulse amplifier, the initial fast rise due to the collection of the electrons, which have a very high mobility, is amplified but the succeeding slow potential change due to the motion of the heavy ions is rejected (figure 1).

The resolution of the counter is thus determined by the transit time of the electrons produced and in a fission counter, where high fields and small spacings are common, this collection may be complete in 100 mμsec or less. Such a counter may thus be used at rates up to 10^6 cps or more.

It is common practice to use proportional counters also with short time constants in the associated amplifier but here the major part of the pulse is produced not by electron avalanche but by the motion away from the wire of the resulting positive ions. This leads to a different pulse shape from that in the ion chamber. In spite of the very high field these do not



Pulse shape in a proportional counter shows the effect of short time constants (Fig 2)

move as rapidly as the electrons in an ion chamber and the rise time of the pulse is usually about 1 microsec. Proportional counters are often used with time constants less than this since some improvement in resolution is obtained at the expense of pulse height (figure 2). The useful upper limit of count rate is however about 3×10^5 cps.

Both electron collection ion chambers and proportional counters require high gain pulse amplifiers in order that they may be used with conventional pulse counting equipment, and the resolution of the amplifier must also be

TABLE I Decay times of common phosphor materials

PHOSPHOR	DECAY TIME, SECS	PHYSICAL FORM
zinc sulphide (Ag)	3×10^{-6}	*polycrystalline screen*
sodium iodide (Tl)	$2{\cdot}5 \times 10^{-7}$	*single crystal*
potassium iodide (Tl)	$1{\cdot}5 \times 10^{-6}$	*single crystal*
naphthalene + 0·1% anthracene	6×10^{-8}	*single crystal*
anthracene	3×10^{-8}	*single crystal*
stilbene	6×10^{-9}	*single crystal*
p-terphenyl in polyvinyltoluene	3×10^{-9}	*solution in plastic*
p-terphenyl in toluene	3×10^{-9}	*solution*

considered as it is often comparable with that of the counter. For example the standard pulse amplifiers Type 1049, 1430 or 1515 have a rise time of the order of 100 mμsec which may be ignored when used with a proportional counter but must be allowed for with a fission counter. Uncertainty about the effective resolution of a counter-amplifier combination makes counting loss corrections difficult to apply and it is common practice to introduce a longer, well defined resolving time in the counting equipment so that the correction may be accurately made.

In a scintillation counter the light output of the phosphor rises exponentially in a very short time to its maximum value and then decays relatively slowly, and the resolving time is determined by the decay time. Table I shows the value of the decay time for a number of common phosphors. It will be seen that organic phosphors in particular are capable of very high resolution. The high output of the associated photomultipliers requires little further amplification so that the good resolution of the counter may be used more easily than that of, say, a fission counter. This high resolution is only of limited significance as far as high count rates are concerned since it is usually possible to reduce the sensitivity of a counter to obtain a moderate count rate, but it is very valuable where small time intervals have to be measured accurately, as for example in coincidence counting or time of flight measurements, and in the presence of high background levels.

Many counting applications would be ideally met by the use of geiger counters but for their limited counting range due to relatively long resolving times. The build-up of the discharge and the dispersion of the positive ion sheath occupy a long period after each event during which the counter is insensitive. In organic quenched counters this total period may be as much as 500 microsec but is more commonly about 300. Halogen quenched counters generally have rather shorter resolving times from 150 to about 40 microsec for a small counter.

With all geiger tubes, however, the resolving time is not stable to better than a few per cent and is affected by operating conditions so that it is usual to swamp the counter resolution with a longer resolving time in the counting circuits. The loss due to this defined resolving time t may be corrected for using the expression*

$$n_t = \frac{n_o}{1 - n_o t}$$

where n_t is the true count rate and n_o the observed value.

This limits the count rate for accurate work with geiger tubes to the order of 10^3 cps or less but many applications such as survey meters and dosimeters involve the use of simple rate-meters. With the lower accuracy obtained with these, adequate corrections may be applied in the calibration up to several thousand cps.

TABLE II Upper limit of count rate for common detector/amplifier combinations

DETECTOR	MAX COUNT RATE, CPS	AMPLIFIER
organic-quenched geiger counter	10^2	—
halogen-quenched geiger counter	5×10^3	—
proportional counter	10^6	*high gain wide band amplifier*
electron collection ionization chamber	10^6	" " " " "
scintillation counters:		
ZnS phosphor	10^5	*low gain wide band amplifier*
alkali halide	5×10^5	
organic or plastic phosphor	10^6	

The range of measurement required thus determines the preliminary choice of a counter. The useful upper limit of count rate for the principal types of detector is shown in Table 2.

Effect of background radiation

The nature and strength of the background radiation in which measurements must be made has a profound influence on the choice of detector. The simplest detectors to use—ionization chambers, scintillation counters and geiger counters in d.c. circuits, and geiger tubes as pulse counters—offer no inherent discrimination against unwanted radiation other than that provided by their relative efficiencies for different radiation. This may be estimated in any particular case and a choice of detector may be made with the most favourable efficiencies. An example of such a choice is the use of a plastic phosphor with a high beta efficiency, using the most favourable geometry for the betas to be counted but having a low gamma efficiency and the minimum possible volume to reduce the count due to background gammas.

For the detection of neutrons d.c. ionization chambers are made with a light alloy structure and low atomic number filling gases to reduce the gamma sensitivity as far as possible. Similarly for beta counting geiger tubes are made with the minimum cathode area consistent with good geometry and low atomic number materials to reduce the gamma sensitivity. Table 3 shows the efficiency of geiger tubes as a function of gamma energy. The d.c. detectors may usually only be used when the effect of background can be reduced by these methods to negligible proportions or when a measurement of the background alone may also be made. The measurement of background level in the absence of the wanted signal when using pulse counters may be used to reduce the effect of background up to the point where the background count rate is some ten times that of the wanted radiation. Beyond this, however, discrimination against background may only be accomplished by using the difference between the amount of ionization produced by different types or energies of radiation.

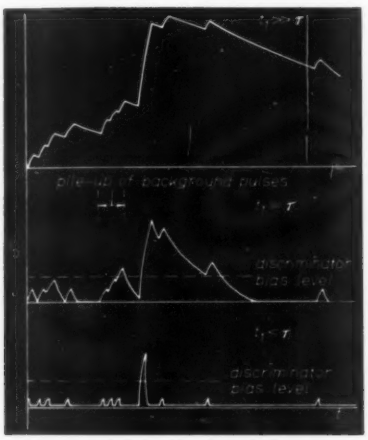
TABLE III Relative efficiency (%) of counters with different wall materials for gamma background

ENERGY *MeV*	CATHODE MATERIAL *Pb*	*Al*
0·9	1·0	0·2
0·4	0·8	0·15
0·6	0·7	0·25
0·8	0·7	0·4
1·0	0·9	0·5
1·5	1·2	0·9
2·0	1·5	1·2
2·5	1·8	1·5

Detectors such as proportional counters, fission counters and scintillation counters produce output pulses whose amplitude is dependent on the nature and energy of the incident radiation. By rejecting pulses below a chosen height or selecting those falling in a narrow range of heights, a very large degree of discrimination against unwanted radiation is possible.

*This formula and that for counting loss due to detector resolving time ($n_o = n_t \exp(-n_t \tau)$ are seen to to be in close agreement for the lower count rates if they are both expressed as series expressions for n_t, when the first two terms are identical.

It is usual in using detectors in this way to make their efficiency as high as possible to the wanted radiation at the expense of background, just as for the simpler types. For example, the problem of counting 50 keV X-rays in the presence of 1 MeV gammas may be attacked by using a small alkali halide phosphor, which has a high efficiency for the X-ray but is too small to be efficient for the high energy gammas, and rejecting the photomultiplier output pulses that fall either side of a narrow band of heights corresponding to the X-rays. High discrimination against gamma rays is obtained in a BF_3 neutron counter as the alpha pulses from the neutron reactions with boron–10 are



Effect of differentiating time constant t_1 on the output waveform of a 'proportional' pulse counter counting alpha particles in the presence of a gamma background. τ = rise time of detector pulse (Fig 3)

many times larger than the pulses due to gammas. Simple pulse height discrimination is adequate in this case.

Discrimination against background radiation which relies on pulse height becomes less effective, however, once the background pulses occur at intervals shorter than the resolving time of the detector/amplifier combination. Once this level is reached the pulses occurring within the resolving time 'pile up' on one another and may pass the discriminator (figure 3). The treatment of this effect is too involved for a short article but it is adequately dealt with in the literature (*1*, *2*). A detector with a short resolving time must be used in these circumstances but the limit is more commonly set by the counting equipment rather than the detector.

A further technique has recently been described (*3*, *4*) which permits the counting of heavy particles in the presence of an intense background of gamma or beta radiation and vice versa. This depends on the difference in the nature of the charge distribution produced by the different particles in certain organic phosphors, which yields an output pulse shape which is characteristic of the particle. By means of suitable pulse handling circuits either type of pulse may be rejected and it is possible for example to count weak capture gamma radiation in the presence of the intense flux of neutrons which is exciting it.

A method of background rejection which is of great value in experiments at very low count rates, particularly where the background is due to cosmic radiation which cannot be absorbed by shielding, is to use two or more similar counters in an anti-coincidence circuit, only one of which can see the radiation to be measured (*5*). Any count which is recorded by more than one counter is then due to background and is rejected, those produced only by the counter exposed to the wanted radiation are accepted. Instead of a group of counters a special double counter may be used in some cases, where the main counter is surrounded by an annular coincidence counter.

Statistical considerations

The lower limit of useful operation of pulse counters is set not only by the difficulty of distinguishing the counts from those due to background from naturally occurring radioactive materials present in the counter, from its surroundings and due to cosmic rays, but also by the random nature of the nuclear processes themselves.

It may be possible by the use of pulse height selection to reduce the natural background count to a fraction of a count per minute, but where the count rate due to the experiment is low a very long counting period is required to provide a reasonably high statistical accuracy. The standard deviation for a mean number of counts $\bar{N}$ for a period t is given by

$$\delta = \sqrt{\bar{N}} \quad \text{where } N \text{ is large}$$

and the standard deviation in the counting rate is then

$$\delta_t = \frac{\sqrt{\bar{N}}}{t}$$

This expressed as a percentage of the mean count rate is

$$\delta_t = \frac{100}{\sqrt{\bar{N}}}$$

The error is then less than δ_t in 68% of cases and less than $2\delta_t$ in 95%.

Thus for an error of 1% in an experiment a total of about 40,000 counts must be taken which may involve very long counting times. This must be considered when making the choice of detector.

Where the background count rate is comparable to or greater than that from the wanted radiation and it is to be allowed for by a separate measurement of background, the time required for this must be considered in assessing a counter.

If the count rate for background alone is n_b and the total rate n_t, then that due to the wanted radiation is

$$n = n_t - n_b$$

and the standard deviation of n is

$$\delta_n = \left(\frac{n_t}{t} + \frac{n_b}{t_b}\right)^{\frac{1}{2}}$$

where t is the total counting time and t_b the counting time for background.

A given available time may be divided between total counting and background counting to give the minimum deviation if

$$\frac{t}{t_b} = \sqrt{\frac{n_t}{n_b}}$$

When the background count becomes as much as ten times the wanted count, the time that must be devoted to background counting is roughly equal to that for the total count and the standard deviation in the wanted count is some six times that obtained for counting for the same time t in the absence of background. Under these conditions the times required for reasonable accuracy become excessive and other methods of discriminating against background must be employed.

Similar statistical considerations apply to the use of integrating detectors at low levels with the additional complication that statistical fluctuations in pulse size due to the varying path lengths of particles in the sensitive volume must be accounted for (*6*).

Careful consideration must be given in planning any experiment involving the detection of radiation to these limitations of detectors caused by finite resolving time, response to unwanted radiation and the random nature of the processes involved. The unfortunate user of radiation detectors has to live with these limitations but a full appreciation of their importance can save many hours of unsatisfactory experiment.

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Prospects are bright for early economic performance in General Electric's new design study of a 60 MW propulsion plant

A BWR for merchant ship propulsion

by R. L. SCHMIDT *and* L. F. FIDRYCH
Atomic Power Equipment Department, General Electric Co (US)

A PRELIMINARY DESIGN of a 22,000 shp system for converting a tanker to nuclear propulsion has recently been completed by General Electric in conjunction with George Sharp for the AEC and Maritime Administration. The direct cycle boiling water reactor system, which was selected by the AEC for this study, is basically the same as the reactor designs which have been developed by General Electric for small generating stations. The plant and equipment designs incorporate mechanical design features which are necessitated by marine service requirements. A full account of the design has just been published in the Proceedings of the 1958 Nuclear Merchant Ship Symposium.

The plant is designed to furnish 22,000 shp and steam for operation of all power plant and ship auxiliaries under normal sea conditions. Figure 1, the heat balance for the plant, indicates the following performance:

Rated reactor thermal output	59·7 MW
Reactor pressure	1000 psig
Steam flow from reactor	205,645 lb/h
Steam conditions	dry, saturated
Feedwater temperature	245°F
Net plant thermal efficiency	27·6%

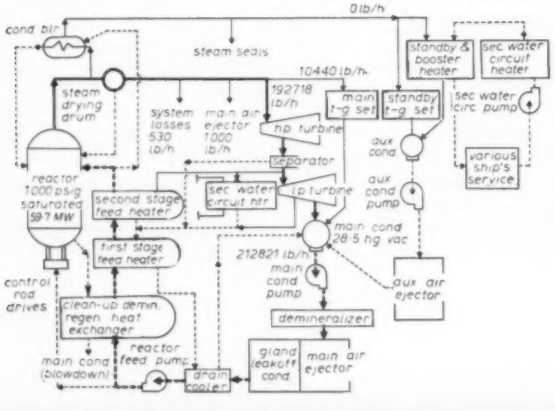
The nuclear steam supply system utilizes a natural circulation, single cycle boiling water reactor, supplying steam direct to the propulsion turbine. A quantity of steam is taken off before the drying drum for the two condenser boilers which generate non-radioactive steam for turbine shaft sealing and ships' service auxiliaries.

The reactor has the following characteristics:

Exit steam quality, core outlet	3·8% by wt
Average central fuel temperature	1440°F
Maximum central fuel temperature	4010°F
Average heat flux (rated power)	76,108 Btu/h.ft²
Maximum heat flux	292,965 Btu/h.ft²
Core diameter (circumscribed circle)	62·75 in.
Active fuel length	68 in.
Water to uranium ratio (no control rods)	2·7:1
Initial enrichment (10,000 MWd/t)	2·1%
Total UO_2 in core	15,523 lb

Water enters the core from the bottom, passes up around the fuel and starts to boil. Boiling continues until the steam/water mixture leaves the core and enters a chimney section which is provided to gain additional driving head.

The steam, which receives initial separation at the water surface, flows through a steam outlet dry pipe in the reactor vessel head and then to an external steam drying drum. Steam at approximately 99·9% quality is available for the propulsion turbine. The water, which is separated from the steam in the reactor vessel, flows down the annulus between the chimney and the vessel wall where reactor feedwater is introduced through a sparger ring, thus sub-cooling the recirculated flow, which then continues down through the annulus to the core inlet.



Under normal sea conditions, natural circulation, single cycle BWR supplies 22,000 shp and steam for operating all power plant and auxiliaries (Fig 1)

UO_2 pellets in zircaloy tubes

The fuel is slightly enriched uranium dioxide, fabricated as sintered solid cylindrical pellets which are stacked in zircaloy tubing, forming a unit fuel rod. The fuel assembly consists of 36 fuel rods in a 6 × 6 array, assembled as an integral unit and surrounded by a removable zircaloy channel. The assemblies have sufficient structural strength to prevent distortion during operation and handling during reactor loading. 88 fuel assemblies in a vertical cylindrical array, accommodating 21 cruciform control rods between the channels, comprise the core.

The reactor vessel is fabricated of carbon steel, clad internally with stainless steel type 304, and is designed for a maximum operating pressure of 1250 psig. Access for refuelling is through the reactor head closure which contains the steam outlet and safety valve penetrations. Thimbles welded to the bottom head provide penetrations and support for the control rod drives.

Each control rod has an individual

drive mechanism, housed in the thimble attached to and extending below the reactor vessel. The drive mechanisms are hydraulically operated, and the control circuit is interlocked to prevent operation of more than one mechanism at a time, except for scram or controlled reactor shutdown. Hydraulic accumulators, one for each two drive mechanisms, charged with feedwater to 1250 psig, will furnish the motive power for reactor scram.

Liquid poison system is a backup for the control rods, and is used only if a sufficient number of control rods to achieve plant shutdown fail to enter the core. The system provides for the injection of the poison under all reactor flow and pressure conditions and will retain the poison solution in the 'ready' state during normal operation without leakage into the reactor coolant system. Operation of the system is manual by remote means; operating pressure is supplied by bottled nitrogen gas.

Secondary steam separation

As shown in figure 2, the steam drying drum, which provides secondary steam separation, is located in the pressure enclosure. Steam at approximately 99% quality enters the drum through a baffled inlet, passes through the scrubbers and out the top connexion, while the separated water will drain to a point below a partition at the bottom, and then back to the reactor vessel.

Two shell and tube type condenser boilers are arranged so that the primary steam condensed on the tube side will flow back to the reactor vessel by gravity head. The steam generated on the shell side is used for auxiliary services where non-radioactive steam is desired.

The condenser boilers also function as emergency heat exchangers when the reactor is isolated from its main heat sink, the main condenser. The feedwater capacity of both units is sufficient to limit the reactor steam pressure to below safety valve setting for more than an hour after reactor scram from full power. Following this period, feedwater to the condenser boilers can be replaced by the emergency reactor feed pump.

After shutdown the reactor is cooled initially by reducing system pressure and temperature with a controlled steam flow to the main condenser through the bypass valve. After the system reaches 250°F, the flow to the condenser will be stopped and decay heat removed by pumping reactor water through the tube side of the shutdown heat exchanger and cooling it with water from the fresh water cooling system on the shell side.

The reactor control system is designed to control reactor power automatically within the limits of 10% to 100% full load. Power is controlled by proportionally positioning control rods in the core with reactor steam pressure as the controlling signal. The maximum power plant manœuvre the reactor control system can handle, without use of the load control system, will be a load increase from 20% to 85% in 25 seconds (2·6% per second). Faster load changes will be the function of the load control system which utilizes bypass steam to the main condenser to minimize reactor steam flow transients. This is accomplished by a master controller which interlocks and controls the ahead and astern manœuvring valves and the bypass valve.

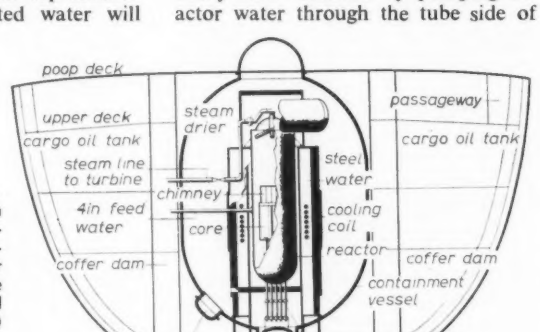
Reactor feedwater is continually conditioned by full flow demineralization of condensate to ensure the removal of corrosion and erosion products and possible condenser leakage of impurities to the feedwater. In addition to two mixed bed demineralizers, the system contains a resin regeneration tank, a resin storage tank, and necessary controls and instrumentation for either manual or automatic operation.

Waste disposal overboard

Provisions are made for limited shipboard storage and concentration of liquid wastes and spent resins. The waste collector tank serves as a central point from which all liquid wastes are handled. Samplers in waste lines discharging overboard in combination with integrating flow recorders will permit maintaining a complete record of discharge quantities and activities.

Non-condensables from the main condenser air ejector establish the requirement for the off-gas system. These gases will include radioactive N-16, O-19, and similar radioisotopes formed by irradiation of reactor water, hydrogen and oxygen from decomposition of reactor water, air leakage into the turbine and condenser, and, if fuel element ruptures occur, radioactive xenon and krypton fission gases.

During normal operation, with no fission gases present, the gases removed by the air ejector pass through a catalytic recombiner to reduce the hydrogen and oxygen to water. The remaining gases pass to a compressor



Arrangement of plant in the hull shows the individual control rod mechanisms below the reactor vessel. For refuelling the dome-shaped reactor head closure is removed (Fig 2)

GE favour BWR for propulsion because:

★ It can be installed in an existing merchant ship in compliance with the minimum safeguard requirements of the AEC and US Coast Guard

★ Low fuel costs—estimates are 3·00 mills/shp.h, equivalent to fuel oil costs of $2·00/barrel

★ Thermal cycle efficiency of 27% is closely comparable to current conventional fuel propulsion systems and is a substantial gain over the PWR

★ Major cost advantage over other reactor types: first BWR system and machinery is estimated at 40% less than first marine PWR

★ Gain in cargo dead weight of 6% over comparable conventional ship

★ No restriction on the operation and manoeuvring performance of the ship

★ No major development required for its application to marine propulsion

to reduce further the volume and to a hold-up tank prior to being discharged under water with the condenser cooling water. If fission gases are present in the off gases, it will be necessary to retain the compressed off gas in hold-up tanks before discharge.

The refuelling system, operated in conjunction with a shore facility, is designed to be used during a yearly maintenance period for all nuclear and conventional equipment. For remote manual handling of the fuel assemblies, a grapple is inserted through a hole in a steel shield plate placed on the reactor vessel flange after the head has been removed. Transfer of the fuel to the storage facility is by use of a refuelling cask which is handled by a shore crane.

The main propulsion turbine is a cross-compound, single flow, single admission machine rated 22,000 shp with 192,718 lb/h of inlet steam at 980 psig saturated and exhausting at 1½ in. Hg absolute back pressure, 105 rpm (shaft).

Two uncontrolled turbine extractions for feedwater heating will be supplied; final feedwater temperature will be 245°F. Special consideration is given in the turbine design to the fact that after the first few stages, the steam will have a high moisture content.

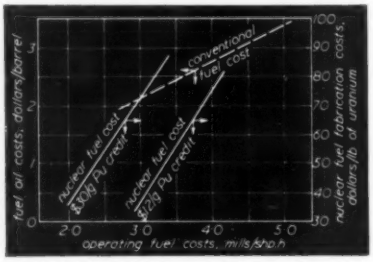
The turbine control system described is designed for normal remote operation from the control room; however, activity levels at part load during startup and shutdown will be low enough so that these operations can be performed locally.

The main condenser is a single pass unit having divided water boxes with internal crossover valves, single inlet and outlet, and horizontal tubes at right angles to the turbine centreline rolled into double tube sheets. Tubes and tube sheets will be 90-10 copper-nickel with 70-30 copper-nickel water boxes. Special considerations will be made in condenser construction to prevent reduction of air inleakage.

In the event of sudden reduction of turbine load, full steam flow can be bypassed to the condenser. Orifices and desuperheating sprays in the bypass system will reduce steam pressure to protect the condenser and turbine. Bypassing steam to the condenser can be done at low loads, during manœuvres, at startup and normal shutdown.

Because of small cargo dead weight and high ship speed, the ship design employed in the nuclear conversion study does not represent the type of tanker which would normally be considered for commercial operation. The results of the design study of conversion to nuclear power identify inherent advantages of the boiling water propulsion system in the areas of low fuel cost and increased cargo carrying capacity.

To evaluate the current relative economic position of nuclear power with conventional propulsion, a cost analysis has been made for both types of ship propulsion under like conditions. In this, a commercial tanker design of 39,000 dead weight tons is employed for both the conventional



In comparing operating fuel costs for nuclear and conventional propulsion the ship was 39,000 dwt, 22,000 shp. The reactor was a 60 MW BWR with 10,000 MWd/t fuel exposure; in the conventional ship, specific fuel rate was 0·50 lb/shp.h and fuel oil heating value 18,500 Btu/lb (Fig 3)

and nuclear propelled ships, and it is assumed that both ships are loaded to the same displacement. No attempt has been made to optimize the nuclear ship economically. It has been assumed that both ships complete 7·5 round trips per year, and both operate 300 days per year at rated propulsion power.

Lower operating costs

A nuclear tanker incorporating a BWR has lower fuel costs than a conventionally propelled tanker. Based on reasonable objectives for reductions in nuclear fuel fabrication costs, it can be demonstrated that operating fuel costs for the boiling water reactor may, except for inflationary trends, remain constant at a level comparable to fuel oil costs of $2.00 to $2.20 per barrel.

Figure 3 is a comparison of operating fuel costs for nuclear and conventional ships, both incorporating a 22,000 hp propulsion plant. This comparison demonstrates that with a fuel oil price of $3.00/bbl, operating fuel costs for the conventional ship are 4·4 mills/shp.h. Based on nuclear fuel fabrication costs of $70/lb of uranium and with $30/gram plutonium credit, the operating costs for the nuclear ship will be 2·9 mills/shp.h. This nuclear fuel cost is equivalent to fuel oil costs of $2.00/bbl. Foreign operated reactors are at present guaranteed $12/gram plutonium credit; therefore, the operating fuel costs for a foreign nuclear ship will be 3·85 mills/shp.h

It is expected that the $30/gram plutonium credit which is guaranteed by the AEC to the end of 1963 will thereafter be gradually reduced and approach $12 to $14/gram. As a result of improved fuel manufacturing practices, it is expected that nuclear fuel fabrication costs in the period 1965–1966 will be reduced to $40 to $45/lb of uranium. With the lower fuel fabrication costs, and a $12/gram plutonium credit, the operating fuel costs for both domestic and foreign nuclear ships will be 3·19 mills/shp.h.

Table I, which compares the ship and cargo weights for the conventional and the nuclear vessel, indicates that the nuclear ship has a 2500 ton increased cargo capacity with a 900 ton reduction in total dead weight. It can annually deliver up to 20,000 additional tons of cargo. It is estimated that the cost of the conventional tanker is $300 per dead weight ton. The cost of the first nuclear ship, BWR-I, is estimated to be $4 million more than the conventional ship. For a second nuclear ship, BWR-II, which

TABLE I

Comparison of ship and cargo weights (weights in long tons)

	CONVENTIONAL	NUCLEAR
Displacement	49,660	49,660
Light ship and weight	10,750	11,650
Total dead weight	38,910	38,010
cargo	34,780	37,360
fuel	3,830	350
miscellaneous	180	180
crew	120	120
Annual cargo capacity 7·5 round trips per year	260,000	280,000

also is not optimized for nuclear propulsion, it has been assumed that the cost of the nuclear system equipment and installation will be reduced 20%.

From this economic evaluation, the following conclusions are indicated:

1. Based on the assumptions employed, a boiling water reactor propelled tanker, initially operating in 1961, offers economic performance within 5% of a conventionally propelled tanker.

2. Considering the long-range trend in fuel oil costs, this first tanker may be economically competitive with conventional propulsion in 5–10 years.

3. The capital charges and interest charges for nuclear ships may always be higher than the corresponding costs for conventional ships. To offset these higher operating costs, a nuclear design must take advantage of the lower fuel costs and increased cargo capacity.

Internal inspection of fast reactor fuel elements

by C. D. REID, *UKAEA Industrial Group, Capenhurst*

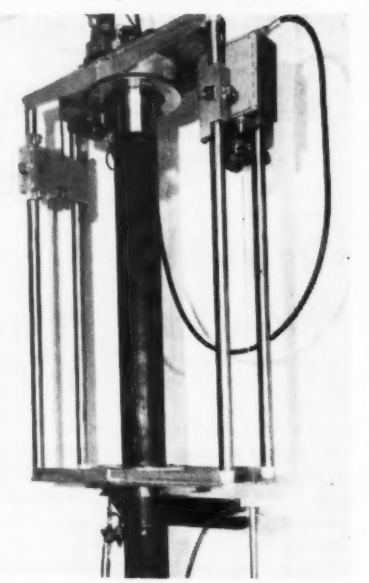
THE useful life of fast reactor fuel elements has yet to be determined; it is likely to be limited by the distortion of the element caused by physical changes taking place in the uranium under the influence of temperature and irradiation. Consequently, for some time after the Dounreay fast reactor has started, a close watch will be kept on the behaviour of typical fuel elements. From time to time specimen elements will be withdrawn from the reactor core and subjected to searching examination so that predictions of the useful lives of the remaining elements may be made.

The fuel elements have been described in a summary in an earlier issue of this journal (*1*). They are tubular, about 4 ft long and 1 in. in outer diameter, and have an inner tube about $\frac{1}{4}$ in. in diameter running practically their full length. After service in the reactor core these elements will be highly radioactive, and may generate sufficient power to raise their temperature to an equilibrium level of several hundred degrees centigrade in free air.

The problem therefore arose of devising an inspection apparatus to enable the bore of the inner tube to be examined for possible damage. It was to be designed to give the maximum amount of information from the bore, and particular emphasis was placed on changes in diameter, sudden restrictions in the bore and cracking. Changes in straightness were not included because the fuel element itself is somewhat flexible. The probes used for inspection are also flexible, and consequently it is impossible to determine some forms of deviation from circularity in the bore.

The prototype apparatus described here was designed to provide optical inspection of the bore and a measure of its diameter.

At the time of inspection the fuel element will be highly radioactive and also, if left to itself, comparatively hot. The radioactivity is sufficiently high to require the inspectors to be screened by a suitable biological shield, and because of its temperature the fuel element must be cooled sufficiently to allow the instrument probes to be used. Since the probe may pick up radioactive matter the apparatus must be designed to allow easy decontamination. All measurements made by the probes require remote presentation, and the inspection apparatus has to be worked by remote control.



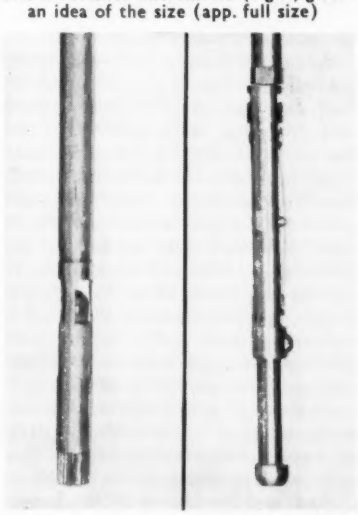
The prototype instrument. Top right is the TV camera with below it the introscope probe. The micrometer probe is on the left of the rotatable headpiece which is fully interlocked

The prototype apparatus has demonstrated the types of inspection which can be made, and has shown that it is possible to control the inspection from a remote station.

Figure 1 shows the prototype inspection apparatus. It is in the form of a two-station capstan carrying a pair of probes which can in turn be brought over and passed down the element under test. The probes mounted were an inductance gauge used for measuring the bore of the fuel element, and a television-introscope which allowed optical examination of the bore. The capstan was designed so that each probe could be located over the axis of the fuel element to within $\pm 0{\cdot}005$ in. The fuel element was held in a V-block clamp, and this and the capstan lock were operated pneumatically. The capstan could be rotated through 180° by a reversible motor, and the probe carriages could be raised and lowered at variable rates. Interlocks were provided so that the capstan could not be rotated if a probe was inserted in the fuel element, nor could the probe carriages be moved from their upper positions unless the capstan was locked in position.

The internal micrometer is essentially a variable inductance, the value of which depends on the diameter of the bore. The model made has a range of about $\pm 0{\cdot}015$ in.; this is limited by the configurations of the micrometer and bore. The calibration is approximately linear and the constructional materials give a good temperature compensation; hence the upper temperature limit at which it may be worked is set by the quality of the insulation used. The model made showed no appreciable change in characteristics in the range between room temperature and 200°C. The micrometer head is shown in close-up view in figure 2, also the head of the

Close up of the introscope head (left) and inductance micrometer (right) gives an idea of the size (app. full size)

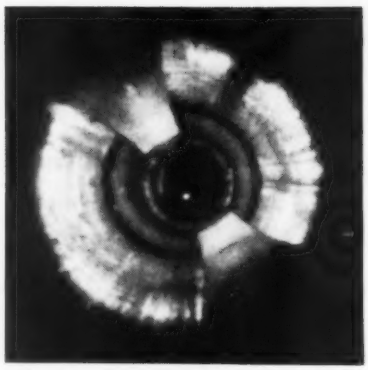


introscope; it was mounted at the end of a 42 in. tube so that it could be inserted the full length of the fuel element bore.

The television-introscope was a combination of instruments. The introscope was specially designed and made for this application by the Foster Instrument Co Ltd of Letchworth. The television chain, made by Pye Ltd was one of their closed-circuit 625-line industrial systems. The introscope gave an annular view of the bore: a typical image is seen in figure 3. The light carried at its extreme tip can be seen in figure 2, and the mounting of the introscope and television camera is shown in figure 1.

To safeguard the probes in case of jamming in an element, they were supported at their upper ends on conical seatings. If a jam occurred, the probe lifted out of its seating, a circuit was broken, and the movement of the carriage was stopped.

The display unit carried the television control unit and monitor screen, the internal micrometer, depth-of-insertion indicators for both probes, and the necessary push-button type switchgear which operated the locking clamps, capstan rotation and carriage movements. The best operating speeds were found to be such that a complete scan with the television-introscope took about 15 minutes, while the internal micrometer scan took about 8 minutes. The introscope definition was good enough to show scratches as small as 0·001 in. wide, and defects larger than 0·004 in. could be defined. The depth of bore under examination by the introscope at any time is about 0·25 in.



The introscope definition is sufficient to show up one thou. scratches

The useful life of the introscope could be limited by several factors: acquired radioactivity, failure of the lamp, and loss of transparency in the lenses caused by their darkening under gamma-radiation. The useful life of the micrometer appears to be limited only by accidental mechanical damage.

The feasibility of inspecting and measuring the bores of fuel elements has thus been demonstrated on the prototype apparatus. It was also shown that the necessary operations could be controlled from a remote station, and the results presented there. The prototype apparatus, however, did not take into account some operational requirements such as ease of maintenance and ease of decontamination.

The experience gained has been passed to Pye Ltd, of Cambridge, who are designing and manufacturing the final model of internal inspection apparatus.

Acknowledgment

This article is published by permission of Sir Leonard Owen, Managing Director, and Dr. H. Kronberger, Director of Research and Development of the United Kingdom Atomic Energy Authority (Industrial Group).

Reference

1. NUCLEAR POWER, 1957, *2* no. 16, pp. 329-330. The DFR fuel element.
Kendall, J. W., and Tottle, C. R., 1957, B.P. 778,881. Improvements in or relating to fuel elements for nuclear reactors.

Nuclear Technology Processes

Separation of multi-curie krypton-85

by E. J. WILSON and K. J. TAYLOR, *AERE, Harwell*

THE gaseous fission product krypton 85 has already proved to be a most useful and versatile radioisotope. The factors of long half-life (10·4 years), moderate β-radiation energy (E_{max} 0·67 MeV with γ-rays of 0·52 MeV associated with 0·65% of the disintegrations) and chemical inertness, show the potentialities of this isotope.

Applications have included: underground tracing of gas in oil fields; leak detection in underground gasification of coal; static elimination; stabilization of breakdown voltages in discharge tubes; beta thickness gauge and *Bremsstrahlung* sources. In addition, an important new application has recently been demonstrated in the preparation of 'light sources,' which rely on the excitation of a suitably prepared phosphor coating by the beta radiation of krypton 85. These 'atomic lights' have many potential industrial and commercial applications.

The increasing demand for this radioisotope, together with the desire to have a ready supply available to influence potential users both in Europe and the United States, has led to the erection of a remotely controlled glass apparatus, which is capable of producing 25 curies of krypton 85 each working day from a starting material containing 10 ppm. (by volume) krypton 85. This is fully described in UKAEA report no. AERE I/R 2693 of which the following is a brief summary.

The raw material for the extraction is the gas evolved from the fumeless dissolving plant at Windscale, the composition of which varies (H_2, N_2, CO, NO, O_2, A, CO_2, N_2O, Kr and Xe, with traces of hydrocarbon gases). The process involves catalytic decomposition of N_2O, absorption of CO_2, liquefaction and distillation under reflux to remove the less condensable gases, a charcoal chromatographic process for separating krypton from xenon, a chemical purification to remove all gases other than inert ones from the krypton fraction, and means of removing xenon as a useful by-product. Although the design of the condensing head of the liquefaction stage of the apparatus is such that deposits of solid N_2O and CO_2 will not seriously impede the rate of condensation and distillation it is desirable to maintain the Kr/Xe fraction virtually free of these gases to prevent their interference during the chromatographic separation.

The resultant pure product is sampled for mass spectrometric analysis, before transfer to storage. A typical analysis is given in the table.

It has not yet been possible to check how quickly the CuO catalyst becomes poisoned by N_2O. No decrease in efficiency of decomposition was observed after 120 litres of N_2O had been processed. This corresponds to about

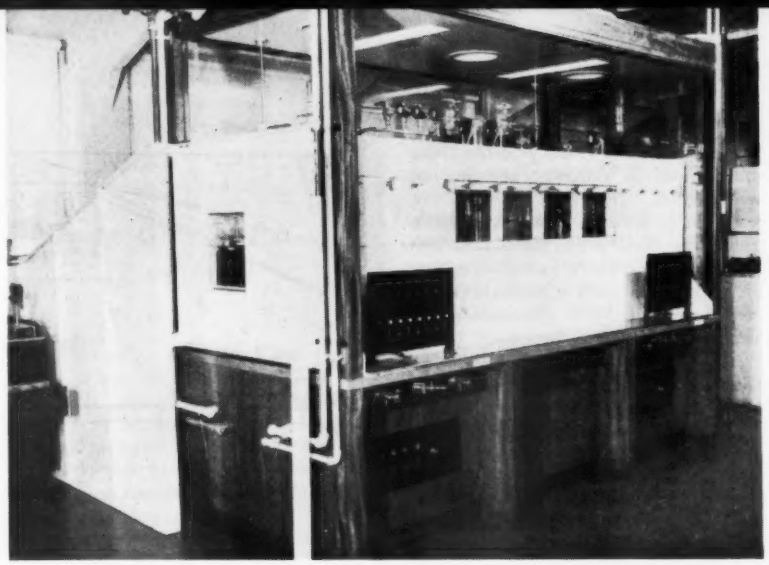
Typical analysis of pure product (percentage v/v$_0$)

NORMAL Kr	FISSION Kr	FISSION Xe	16 CH_4	28 N_2	32 O_2	40 A	44 $N_2/O/CO_2$	2 H_2
49·0	50·5	0·0025	0·0038	0·18	0·001	0·025	0·089	0·24

Krypton 85/Krypton 3·37% Krypton/Total Gas 99·5%
The recovery of Krypton 85 is greater than 99%

12,000 litres dissolver gas. Experiments with CuO as wire, have shown that the catalyst has been partially renovated by passing N_2 through the hot bed for a number of hours. The small plant is not yet equipped with a duplicate N_2O decomposer, nor a detector for indicating the break-through of appreciable quantities of N_2O.

It is not considered economical or practical to adopt this method of purification for a full scale plant. Even preliminary concentration of the inert gases by adsorption on a large activated charcoal bed at reduced temperatures is not efficient enough. It was found that by using a spiral shaped chromatographic column, diameter 0·7 cm, length 290 cm, containing 65 g activated charcoal cooled to −80°C, the krypton concentration was only increased by a factor of 7 before the krypton broke through. A more economical method involving solvent extraction has been developed. It has been estimated that a moderately sized plant operated with CCl_4 at atmospheric pressure will separate krypton and xenon reasonably effectively from the less considerable gases. Such a process could be followed by a charcoal chromatographic process, similar to that described in this paper, to separate the krypton from xenon by a batch-wise process. It will still be necessary to decompose N_2O catalytically before the solvent extraction.



The complete process—catalytic decomposition of N_2O, absorption of CO_2, liquefaction and fractional distillation, charcoal chromatography and purification—is carried out a shielded fume cupboard

Nuclear Technology | Materials

Plutonium metallurgy in Russia

by M. B. WALDRON, *AERE, Harwell*

TO the metallurgists at the first Geneva Conference in 1955, Russia played one particularly spectacular trump card. While Western delegates were preparing to enthuse on the relaxation of American security which permitted the substantial publication of crystallographic data on plutonium compounds, Konobeevsky flashed on to the screen a series of complete and detailed phase diagrams, originally published at the rival Iron Curtain Conference in Moscow a short time previously. A further surprise was in store for those who managed to secure from the Russian delegation a copy of the hastily-produced bound record of the Moscow conference; it was claimed that all the work, which in most cases excellently paralleled known US and UK achievements, was done by refined techniques using samples measured in milligrams or even micrograms. Coupled with the first stories of the expansion of Russian technical training establishments, one might wonder whether the use of micro-metallurgical techniques enabled plutonium research to continue in numerous provincial centres by sidestepping the limitations normally caused by the extreme radioactive toxicity of this material, while plutonium research in the United Kingdom, Canada and the States was confined to a handful of specialized laboratories. It was with more than average impatience that some further indication of Russian progress was awaited.

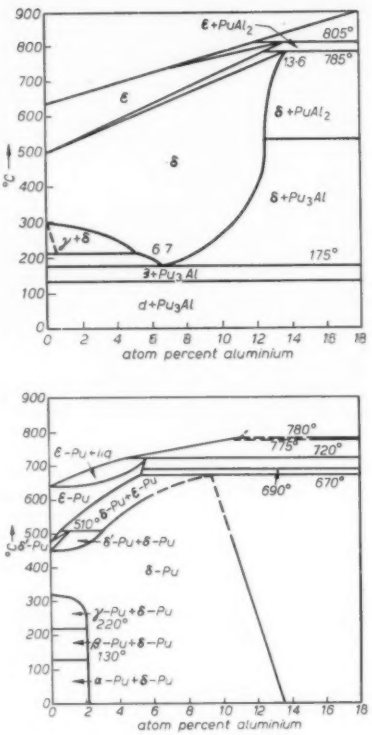
Disappointment at Geneva

Russian delegates to a Physical Society meeting at Aldermaston Court in which British papers on plutonium metallurgy were read disappointed any who hoped to hear of Russian work, since they did not participate in the proceedings. Informal conversation merely established that work was continuing. Visits of Russian scientists to the Harwell laboratories led only to the statement that similar apparatus was used in the USSR. It was therefore left for the Second Geneva Conference last September to establish the rate of Russian progress.

The papers circulated in advance of the meeting were frankly disappointing. Shorn of experimental particulars they presented much of the old material, amplified here and there by new information. Some points of detail were modified without comment while the bare presentation enabled little critical comparison with British, American or other available results to be made, where differences appeared. One thing that did stand out, however, was the unanimity between the major countries in the systems found worthy of close study. Thus the US, UK and USSR had all studied the plutonium alloy systems with aluminium, iron, thorium and uranium; both Britain and the Soviet Union had also studied closely plutonium-zirconium alloys and the related systems with titanium and hafnium. The degree of general agreement, to those who appreciate the difficulties attending work of this kind, was gratifying; the differences sometimes merely reflected areas in which one laboratory had bestowed more attention than the others, sometimes needed close investigation. One field in which the Russians had worked almost alone—an academic one—was the investigation of the magnetic properties of plutonium alloys and intermetallic compounds. The comparison between analogous plutonium and uranium compounds shows a very variable behaviour of the plutonium atom, consistent with other indications of the

variable effective valency of the plutonium atom in different alloying environments.

As far as Russian research on plutonium was concerned, the actual conference proved more informative than the papers. My own impressions of the conference, in this connexion, are largely dominated by two things. Firstly, the experience of entering the Russian scientific exhibit and, after circumnavigating the famous replica of Sputnik 2, seeing a large-scale reproduction of all the Russian plutonium alloy diagrams, and chatting time and time again, for as long as the interpreters could manage, with one of the plutonium metallurgists who had participated actively in the work and found it as exciting as ourselves. Secondly, the use by the Russians of Brinkman pressures at temperatures in the region of 200°C, to induce transformation to occur which would be favoured thereby, as a first step to the study of sluggish reactions. This technique, for example, was used by them to establish the eutectoid horizontal at 175°C in their version of the plutonium-aluminium system, in contrast with careful British work which suggests complete delta-phase stabilization down to room temperatures (figures 1 and 2). Differences in other phase diagrams can be attributed to the use of this technique, the validity of which as a means of securing true equilibrium, is, in the view of the writer, highly questionable. Whilst the use of pressure in this way is a recognized way of accelerating reaction



Comparison of Russian (top) and British (bottom) plutonium/aluminium system diagrams reveal marked discrepancies, due to the different techniques used in obtaining them (Figs 1 and 2)

rates, its application to extremely sluggish reactions may lead to the retention after removal of pressure of a non-equilibrium structure whose apparent stability may be deceptive.

Two salient points arose out of the various discussions that took place. One was that the use of micrometallurgical techniques has been largely abandoned in favour of full scale operations, usually in gloveboxes of a conventional kind. The other point was that the use of a vacuum better than 10^{-6} mm Hg is considered adequate to obviate the need for glovebox operation for such processes as melting and casting of 100-gram ingots. Both the scientist and a health physicist maintained that no release of activity could normally be detected, even on opening the furnace at the end of a run. Although they appear genuinely to adopt the same standards of radiological protection as ourselves, this practice seems to be at variance with British experience. It also seems that some eight laboratories in Russia, under the control of the Moscow Institute for Advanced Studies, undertake plutonium metallurgy research, employing between them 100–200 graduate staff.

Undoubtedly, the opportunities which were afforded at Geneva for contact between plutonium workers in Russia and those in other countries will stimulate further fundamental studies, if only to resolve the differences that have emerged. Whatever may be the outcome of this endeavour, it would seem that a fruitful field of scientific discussion has been initiated and that the Russians are well equipped to make their contribution to future progress.

Nuclear Technology | Irradiation

Strontium determination in organic matter

A standard method for the radiochemical determination of strontium 89 and strontium 90 in vegetation, fish and seaweed ash has been worked out by the Chemical Services Department of the UKAEA Industrial Group's Operations Branch at Windscale. In the method, which is fully described in report no. IGO-AM/W-185, strontium carrier solution is added to a weighed portion of the ash; nitric and perchloric acids are added and the solution is evaporated almost to dryness. The residue is dissolved in water and silica is removed by filtration.

Calcium and strontium are precipitated as phosphates and the strontium is separated by a series of precipitations as nitrate. A barium chromate precipitation is made, followed by a ferric hydroxide scavenge, to remove radium, daughter elements of radium, and radio-yttrium. The strontium is precipitated as carbonate and mounted on a stainless-steel counting tray; the activity on the tray is measured through an aluminium absorber, thickness 131 mg/cm², using standard g.m. counting equipment.

The strontium carbonate precipitate is transferred to a centrifuge tube, dissolved in acid, and yttrium carrier added. The solution is stored for a period of at least 10 days to allow the yttrium 90 to approach equilibrium. Yttrium is precipitated, twice as hydroxide and finally as the oxalate, filtered and the paper mounted on an aluminium counting tray. The activity on the tray is measured using standard g.m. counting equipment.

Strontium 89 and strontium 90 are individually expressed as $\mu\mu c/g$ of ash by comparison of the observed counting rates with those observed for sources prepared from solutions of known strontium content. The results are corrected for chemical yield of the carriers.

A method for the determination of calcium in the sample ash is included; if required, the observed strontium contents may be calculated with respect to the calcium content in the ash.

The report includes procedures for determining the counter efficiencies to strontium 89 and yttrium 90 and also the preparation of the Sr-89/Y-90 control source.

Automatic foil counting

In the article by M. F. Smith in our March issue there were two errors in the reference viz:

1 Tittle, C. W. *Nucleonics* 1951, not 1955
2 AERE R/R 2703, not 2073

Cross Section by GRACCHUS

UNTIL quite recently, the idea that Mr Cube—that little symbol of the sugar industry introduced as an anti-nationalization gimmick for the general election of 1950 by one of the leading companies—could ever play an important part in atomic energy must have seemed fantastic to his creators. Now however it looks as if he might be the means of rendering graphite impermeable by a very simple process.

Writing in his firm's house journal, Mr D. A. Boyland of the GEC Research Laboratories describes how it's done. Very simply, ordinary graphite is full of small holes which, if we are ever going to hold fission products in high-temperature reactors, must be filled up. The obvious thing to fill them up with is carbon, and sugar—$C_{12}H_{22}O_{11}$, if I remember aright— contains about 42% of it. Thus you merely impregnate the graphite with strong sugar solution and heat it until the hydrogen and oxygen are dissociated, leaving the carbon in the pores. According to Mr Boyland, four or five impregnations followed by bakings can reduce the permeability by a factor of over a million.

In a recent issue of this journal Mr Watt and members of his research team at the RAE, Farnborough, described a similar process using furfuryl alcohol, which has the same effect. The GEC have also had good results from furfural—a similar substance—but believe the simple sugar method is best and are setting up a plant at Powell Duffryn's Hayes works for treating Hunterston channel sleeves at the rate of about 2000 a week. As mentioned in Watt's article, the RAE process is being exploited by Hawker Siddeley. Both types of material were, of course, shown at last January's Physical Society exhibition in London. Taking things a stage further, Mr Boyland hints at a completely impermeable graphite developed at Wembley. This apparently behaves like a metal and is produced by a completely new manufacturing process. Beyond those cryptic remarks, he is however silent. Impermeable graphite has, it need scarcely be pointed out, applications far beyond reactors and a leakproof absolutely incorrodible vessel or heat exchanger must be a chemical engineer's dream.

TALKING about graphite, I was privileged to see the other day a most remarkable experiment—a demonstration in a lecture theatre of Wigner energy being released. The theatre in question was at the Royal School of Mines and the demonstrator Dr A. B. McIntosh, head of the AEA's Culcheth laboratories. McIntosh had with him two very small pieces of graphite, one irradiated and full of Wigner energy, the other as manufactured. To each was attached a thermocouple and both were placed in a thermostatically-controlled calorimeter on the lecture bench. The thermocouples were wired to mirror galvanometers shining on a screen with a third galvanometer spot indicating the calorimeter temperature. On being popped into the calorimeter both graphite spots advanced for a time side by side as their temperature slowly rose. Quite suddenly however, the irradiated spot began to move ahead as the release was triggered off and soon it had moved right off the scale to a temperature well over that of the calorimeter. Before the experiment Dr McIntosh apologized in case it didn't come off because he hadn't had time to try it out before the lecture. He needn't have worried for it brought the house down and showed more than volumes of Fleck reports ever could just what happened at Windscale. I understand the experiment had previously been done at Oxford and I dare say from now on it will prove a top of the bill attraction.

The very much reduced thermal conductivity of irradiated graphite was also demonstrated using a very simple device. Dr McIntosh had a sort of large two-pronged graphite fork, one prong in Wignerized graphite the other normal. Both prongs were placed in a Dewar flask of liquid nitrogen until both were well and truly covered with frost. He then transferred the fork to hot water and the relative rate of advance of the thaw front up the prongs was most striking.

THE European Nuclear Energy Agency could hardly have chosen a more delightful place for their industrial management conference (May 11-14) than Stresa. This promises to be the Agency's most ambitious function yet, with over 50 star speakers from Europe and America and 500 delegates. During the four days, it is proposed to cram in eight full sessions with about two dozen papers covering business aspects of nuclear energy from European programmes, through economics, financing, legal questions and management problems to market prospects for materials, equipment and instruments. In addition to various official social functions there is a visit to the Italian 'Harwell' at Ispra where their new American CP5 is now operating. It sounds a crowded four days.

THERE is a widening and disturbing gap opening up in this country between technology and higher business administration. For some inexplicable reason the management of men and business has never been considered a subject amenable to theory or academic study and we have nothing in this country comparable to the Harvard school of business administration and other American institutions. True, many of our larger businesses run executive's training courses but they are necessarily concerned solely with the company's own problems and the young man who wants to study administration in general at a high academic level has practically nowhere to go.

I was therefore very glad to hear Sir Arnold Plant in his Graham Clark lecture say a few words on his one-year course in Business Administration at the London School of Economics. He pointed out that while British industrialists have been particularly generous and far-sighted in allowing their technical and scientific staff to pursue academic studies in their particular specialization, there has so far been little recognition of the need to encourage those who show an aptitude for it to prepare themselves for higher management and administration. A notable exception is of course Lord Chandos who is giving a valuable lead by sending to LSE each year a number of graduate apprentices who are to be offered permanent jobs with AEI. In the world of atomic energy particularly there is a bright future for what Sir Arnold has called the 'engineer-administrator.' But he can't just be allowed to pick up his administration: he must learn it just as methodically as he learned his engineering.

On Record

France, the one country of Europe which will have a self-contained nuclear industry.—Political and Economic Planning.

Atoms are not all neat round shapes like billiard balls . . . nickel and cobalt (have) six or eight blisters on them.—New York Times reporting American Physical Society meeting.

The radiography of graphite

International cooperation gives lead to Powell Duffryn

EXTENDING THE APPLICATIONS for graphite in nuclear engineering has led to specialized machining facilities being set up and with them, the necessary associated inspection facilities including radiography. To comply with the contract requirements covering some 200,000 graphite components for AEA, Powell Duffryn Carbon Products Ltd have had a complete X-ray installation built at their Hayes factory. This equipment, the first of its kind in the world, was designed by Inspection Equipment Ltd and is the result of very close international cooperation between the designers and the manufacturers of the unit components in America, Denmark and the UK. The design enables 100% radiography to be carried out at the end of the production line following physical and dimensional inspection. While maintaining high quality film output, time and motion research has ensured that all the equipment is operated at maximum speed with minimum labour effort.

Taking the films

To meet the large-scale output, a high degree of automation was incorporated into the design and the 50 kV X-ray set forms an integral part of the final stage of the production line. The cabinet affords complete protection to the operator and there is no possibility of the graphite becoming contaminated by the shielding lead within the cabinet. The X-ray set is fitted with electrical interlocks and the shutters are operated by remote control. In this way, once the radiographic technique has been laid down, quick and accurate radiography is achieved simply by push-button operation.

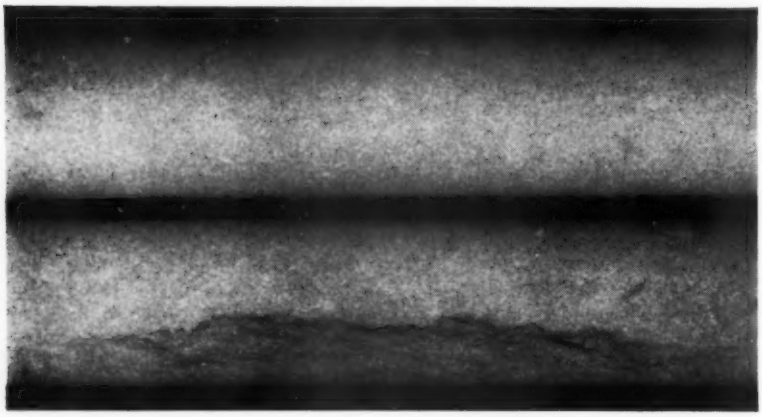
The nature of the graphite makes it necessary for the X-ray tube to give a high proportion of long-wave or 'soft' X-radiation and the US Machlett OEG/50A which gives high intensity long waves was selected. The tube has a thin beryllium window which allows the correct type of radiation to be emitted and the high contrast radiographs obtained greatly improve the defect sensitivity. The tube has a relatively fine focal spot—1·5 mm—and a long focus distance of 48 in. is used in order to radiograph ten graphite components simultaneously. Compared with conventional X-ray tubes, where Pyrex glass is normally used, the beryllium window gives a much greater emission of 'soft' radiation.

To assess sensitivity and establish a suitable technique Powell Duffryn have produced a set of graphite penetrameters. These are in the form of step wedges machined to very fine limits and a radiographic technique has been worked out which can give a 1% sensitivity on the production line. This means that with 1 in. thick graphite, defects representing a thickness difference of one-hundredth of an inch can be seen on the film.

Loading the components

The graphite components are accommodated 10 at a time in the exposure tray. They are so located that when using a 24 in. × 24 in. film two images of each component are obtained. To prevent contamination, lead-free masking is incorporated and the graphite pieces are held in the masking rack on a curved surface to give the exposed film an even density. After considerable research, Kodak 'Crystallex' fine-grain film was finally selected and the envelope packed film is slid into the curved bottom of the exposure tray. Automatic component identification is built in so that any defective graphite component can be easily withdrawn from the production line.

As it will be in production. A section in full size of a 1 in. graphite test bar. The necessity for two exposures of each component is shown by the fact that the defect only appears in one projection



Automatic film processing

After taking the radiograph the unusually large film is automatically processed. This machine, manufactured by the Danish company Refrema of Roskilde, near the Danish Atomic Energy's Establishment at Risö, carries out the developing, fixing and washing of the X-ray film without the need for any attention from the darkroom staff. As the films are untouched by hand, scratches and finger marks are avoided and the variation in results which are inevitable with hand processing are eliminated. The machine is of two main components, the processing and the drier.

The processing section is located in a 'safe-light' dark room where loading, developing, fixing and washing are carried out. An ingenious light trap is located in the wall between the dark and light rooms.

Load it and leave it

The films are loaded, each on its hanger and from this point onwards until the finished films are dried the process is fully automatic. The mechanism lifts the films up and lowers them into the developer, rinse, fix and wash by means of electrically driven endless chains. The films are agitated not only in the developer but also in the fixer and wash so that flow marks and air bubbles are avoided and processing is speeded up. Agitation and movement of the films through the tanks is effected by means of two longitudinal bars which lift the ends of the film carrying-hangers and transfer them along a series of notches. This ensures that there is a fixed distance between each film and there is no possibility of them touching one another.

Temperature control

To maintain the developer solution at a constant and even temperature throughout the tank, a circulating system is provided. The solution is drawn into a small tank by an impeller which pumps it up past an immersion heater and a cooling coil, controlled through a magnetic valve by a contact thermometer. After

being heated or cooled, the solution is returned to the main developing tank. The entire contents of the tank are circulated through this system approximately twenty times an hour. The solution is automatically and continuously topped up from a replenisher tank, located on the outside of the machine.

Time control

The cycle of the machine is set in accordance with film manufacturers' recommended times and temperature but this may be changed through a regulator. Normally, with the gear set to give the shortest times, a film is ready for wet viewing in approximately ten minutes. The time in each bath may be further varied independently by changing the form of the notches carrying the hanger bars.

The drier unit

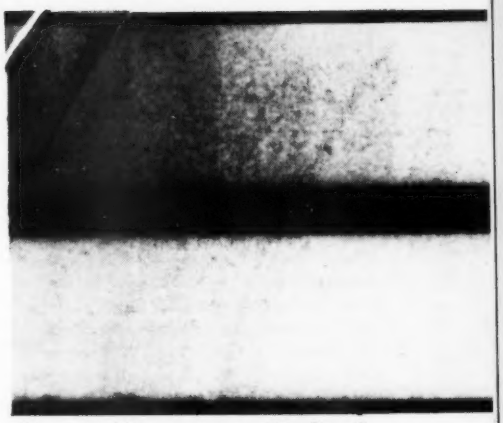
The films move along the drying chamber in which heated air is constantly circulated by four fans on the top of the compartment. When to save time, wet inspection of the films is necessary, they are available immediately they reach the washing tank and can be easily withdrawn from the side of the machine.

The drying system is thermostatically controlled and in the event of an electrical power-failure the complete unit has a warning system. When the films pass from the drier they are held in a storage space which will hold a number of cross bars. An audible alarm is sounded when five bars have accumulated.

Viewing the films

From the storage space in the drying machine, the films are mounted one at a time on the viewer. This was specially designed for optimum viewing sensitivity of each component on the film. A sliding front panel carrying the film is drawn from side to side across a fluorescent light source which is screened so that only the two views of one component are illuminated at a time. This gives the best viewing conditions as it enables the inspector to concentrate on the one component without distraction from the rest of the radiography.

While this complete unit is the first of its kind in the world, the many standard and non-standard components were manufactured and installed and ready for operating within six weeks from the order being placed. The necessity for such equipment underlines the fact that many aspects of nuclear engineering are now emerging from a purely 'one-off' experimental state into normal industrial production runs—such changes do not in any way reduce the special inspection procedures and requirements associated with nuclear components.



X-ray as thickness gauge. The Powell Duffryn penetrameter showing both a stepped (1/100th in. per step) side and a constant thickness side of a 1 in. graphite bar

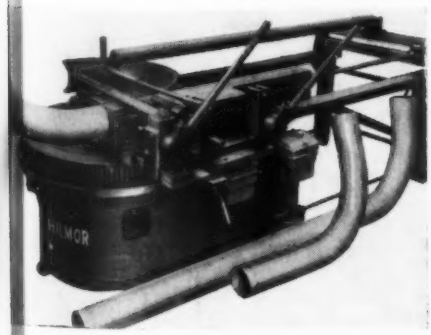
PROGRESS IN INDUSTRY

Manipulating finned tubing

Hilmor machine speeds fabrication

WHEN FINNED TUBING was first introduced it was employed in straight lengths and bent sections of plain tube were employed to meet any particular fabrication shape. In recent months, Hilmor Ltd, manufacturers of tube-bending equipment have been carrying out a series of experiments with finned tubing. A wide range of different types of finned ferrous and non-ferrous tubing have been satisfactorily formed on their standard compression and mandrel type of bending machines.

Bending finned tubing with standard machines. By using specially machined tools, this Hilmor bender can deal with a wide range of extended area ferrous and non-ferrous tubing



Nuclear applications

For use in heat exchangers required for two of the nuclear power stations at present under construction, some 400 miles of 'Integron' finned steel tubing will be incorporated. Tests have shown that this tubing can be successfully formed on standard bending machines. By adopting this method production times and costs are very considerably reduced—a further important aspect for nuclear applications is that welding and its attendant comprehensive inspection requirements are obviated.

Tooling requirements

When compression benders are employed, the formers and guides are machined to suit the outside diameter of the fins. Where mandrel-type bending machines are used, the tooling is machined to suit both the outside diameter of the fins and the bore of the tube. Then, using either types of machines, bending is carried out in the normal way. While the experiments have not been carried out to ascertain the minimum radius which can be bent without distorting the fins, the tests so far indicate that radii for all normal purposes can be made without trouble. In the case of 'Integron' tubing, one size measuring $2\frac{1}{8}$ in. fin root diameter and $2\frac{1}{4}$ in. outside fin diameter was bent to give good quality bends with an inside radius of 5 in. Hilmors are of the opinion that, if required, their machines could make bends of much smaller radii for this size of tubing.

Many new forms of extended-surface finned tubing are available and now that a simple yet efficient production technique can be employed, it will be possible to improve the efficiency of many heat exchangers and other units using finned tubing.

To meet possible advanced designs where internal and external finned tubing is required, Hilmors are experimenting with bending this material and special attention will be paid to the possibility of any 'thinning' of the internal fins which may affect the heat transfer characteristics of the tubing.

New Product Survey

PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

GLOVE BOXES

novel cylindrical types

A new type of glove box, designed to solve the problem of carrying out a series of operations with highly alpha-active materials, has been developed by Boucher & Co Ltd in collaboration with Dr K. W. Bagnall and his co-workers of the Chemistry Division, Harwell.

This cylindrical glove box utilizes a rotating table as the work space, allowing the use of three times the normal work area from one pair of gloves. The rotating table is provided with a cutaway sector for access to a transfer port, where material may be passed from one sealed box to another on a push-button controlled electric trolley running in an interconnecting duct. Access is also provided to a centrifuge and other removable facilities fixed to the base of the glove box.

The front window of the glove box is provided with two sheets of perspex between which a current of air is drawn for extra protection against highly radioactive materials, such as polonium-210, one of the materials which the box is designed to handle. A built-in fire extinguisher is also provided as well as an explosion port at the top. The complete glove box is mounted on wheels for easy transport from one laboratory to another

Tick **No 208** on reply card

CHROMEL-ALUMEL

now freely available in UK

Since their discovery in 1906, *Chromel-Alumel* thermocouple alloys have become the universally accepted standard wherever accurate measurement of high temperatures is needed. They are, in fact, the only base metal thermocouple alloys known which have a useful temperature range up to 1250°C (2300°F). The quality of these alloys is due in large part to their single source of origin, for Chromel and Alumel are produced only by the Hoskins Manufacturing Company in the USA. So closely controlled is the manufacture of Chromel and Alumel, that any batch of Chromel, when used in conjunction with any batch of Alumel, whenever and wherever bought, will give results guaranteed to fall within the limits for new material.

As a result of recent relaxation of currency controls, Hoskins Chromel and Alumel thermocouple wires are now available on a 'same-day' delivery basis from R. G. McLeod Tools Ltd—for many years sole agents and stockholders for these alloys in the UK. For a long time it was thought impossible to maintain a bright finish on *Chromel-Alumel* wires during the long stabilizing heat-treatments required to maintain consistent long-term accuracy. Because of this it has become customary for the tenacious oxide film to be scraped away before making connexions or welding a thermocouple junction. This will no longer be necessary since the new wires are bright.

Tick **No 209** on reply card

WATER TREATMENT

de-ionization plant

If water is passed through a column of one of the synthetic resins in the hydrogen form and then through a column of another resin in the hydroxyl form, the resultant exchange removes not only the bases calcium, magnesium and sodium but the sulphuric, hydrochloric and nitric acid radicles as well, thus producing a pure salt-free water without evaporation and condensation.

Since 1945 great advances have been made in the manufacture of synthetic resins so that production of pure water by de-ionization has now become a sound and attractive commercial proposition. In the *Solobed* system of de-ionization—developed by Paterson Engineering—a water of greater purity than distilled is obtained at lower cost.

The two types of resins, in bead-shaped particles, are mixed together in one vessel. In the smallest unit this is a transparent plastic cylinder and the valves and pipework are non-metallic. Thus, there is no metal in contact with the water—an important point since the water is so pure that the most minute traces of contaminants have a marked effect on purity. In the larger installations, the cylinders are made of steel, lined with acid-resisting material, with windows through which the separation and re-mixing processes can be observed.

The resins are regenerated with dilute acid and alkali solution. The flow of water is first reversed; since one resin is lighter than the other, this has the effect of separating the two types. Dilute caustic soda is introduced at the top of the unit, passes through the upper resin and out at the interface. This resin is then rinsed with water in the same direction to remove excess alkali. Dilute hydrochloric or sulphuric acid is then introduced at the interface, passes through the lower resin and out at the bottom of the unit; this is followed by rinse water in the same direction. Finally the resins are remixed by means of compressed air introduced at the bottom of the cylinder—the resins readily mix.

The smallest *Solobed* unit is capable of treating 15–20 gph; there is no upper limit to capacity.

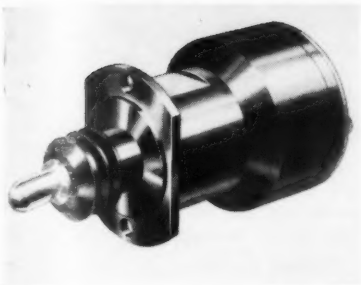
Tick **No 210** on reply card

LIMIT SWITCH

exceptionally rugged

A switch, which has been designed to give maximum reliability under the most adverse conditions that can be envisaged, has recently been developed by Sir W. G. Armstrong Whitworth Aircraft Ltd. Known as the *Comel 3 Reliable Switch*, a typical industrial application would be as a limit switch for machine tools working in difficult environmental conditions.

The following are the details of the environmental tests which have been successfully carried out: steady acceleration of 50 g and an impact of 50 g mean intensity for a duration of 10 milliseconds in six mutually perpendicular planes; no adverse resonances encountered over a frequency search of 20 c/s to 10 kc/s at intensities up to 40 g, together with continuous vibration test over the spectrum for a 10 hour period; dry heat test to + 70°C (7 days); damp heat test at 55°C ± 2°C at 95% relative humidity; cold temperature to −40°C, waterproof to −1½ psi.



The AW switch has a one-piece body of moulded nylon and the movement is completely sealed

The contact resistance is of the order of 10 milliohms and the insulation resistance is 2×10^4 megohms. Values of voltage and current which can be handled by this component are:— 24 volts, 2 amps d.c.; 250 volts, 1 amp a.c.; contact arrangement, single pole, double break.

Tick **No 211** on reply card

RADIATION SHIELDING

heavy metal

Johnson Matthey are now producing and marketing Mallory 1000, a material composed of tungsten in a nickel-copper matrix with a specific gravity of about 16·9. The material may be subjected to all normal machining and grinding processes and is suitable for the manufacture of components where high mass coupled with high strength and small volume are important considerations.

A major application is in radiation shielding. By virtue of its physical structure and its very high density, Mallory 1000 is particularly effective as a gamma ray absorber and it can also be used against neutrons provided the energy is relatively low. Such low-intensity neutron irradiation causes only moderate induced activity.

Mallory 1000 is supplied in special pressed shapes as well as in the form of round and rectangular bars.

Tick **No 212** on reply card

RECOMBINATION CATALYSTS

new BWR types planned

The use of heavy water in a reactor involves the problem of radiolytic gas. This cannot be allowed to accumulate in the sealed system or build up of explosive mixture would occur. Further, the decomposed heavy water, being an expensive commodity must be recombined and returned to the system with the minimum loss.

In the DIDO reactor for example the gas diffuses at about 1 cu. ft. per hour to the surface of the heavy water where it is picked up and swept out of the reactor in a stream of helium. A proportion of this gas mixture is continuously circulated over a recombination catalyst when the deuterium and oxygen are reformed to yield heavy water vapour which is subsequently returned to the reactor. The recombination unit is heated to prevent the condensation of D_2O on the catalyst. The unit selected for DIDO was one of the range of *Deoxo* catalytic recombiners developed and manufactured by Engelhard Industries Ltd. This provides for the continuous removal of oxygen from hydrogen or certain other gases by promoting the reaction with hydrogen to yield water vapour, and will operate at room temperature or higher; the efficiency of the catalyst is such that molecular oxygen concentrations are reduced to well below 1 v.p.m. over the catalyst.

This type of recombiner is ideally suited for operation under the conditions obtaining in the DIDO research reactor. However, with advent of power reactors, particularly those of the boiling water type, there has arisen a need for a recombination catalyst to operate in steam at high temperature and pressure. To meet this requirement the Research Division of Engelhard Industries has recently introduced a new platinum group metal catalyst capable of effecting recombination in steam at high pressures and temperatures; the support material employed in this catalyst is particularly resistant to breakdown under these conditions.

Tick **No 213** on reply card

REMOTE HANDLING

overwall tong

Teleflex Products have recently introduced a new remote handling tool for use with low lead brick shielding walls. Known as the overwall tong, it obviates the necessity for remote handling at fixed stations, is sealed and does not require any maintenance. The unit can be used for gripping, carrying and rotating, and because it is virtually free from backlash, is sensitive and positive in action. It was designed in conjunction with AERE, Harwell.

The control mechanism comprises a flexible shaft, one end attached to an operating mechanism, and the other to a tong head. The body of the unit has an engraved scale of three markings, adjacent to the adjusting sleeve. Maximum and minimum fine adjustments of the tongs are indicated by red marks, and the intermediate position by a white mark.

The support handle is adjustable for position and readily adapted to suit right or left-hand operation. A hook is provided for storage and also for the attachment of a pulley wire and counterweight if required. The weight of the unit with the tongs—which are completely interchangeable is 6¾ lb, without tongs 6 lb.

Tick **No 214** on reply card

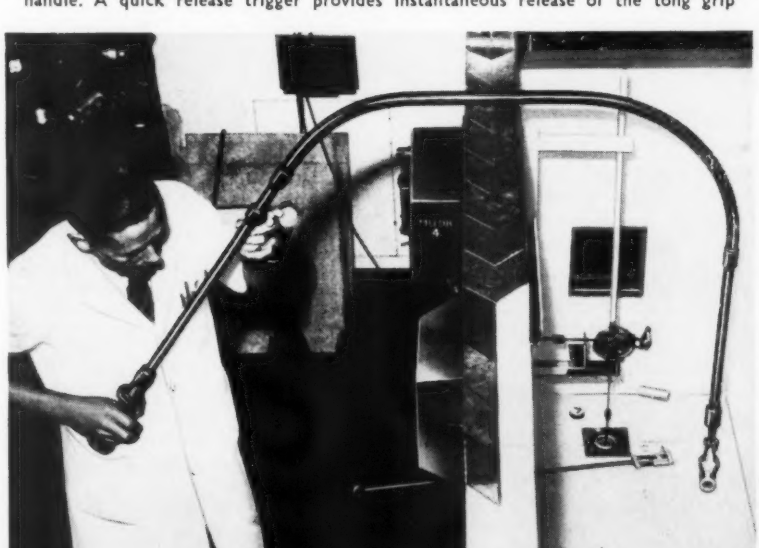
MIXER AGITATORS

spiral bevel drives

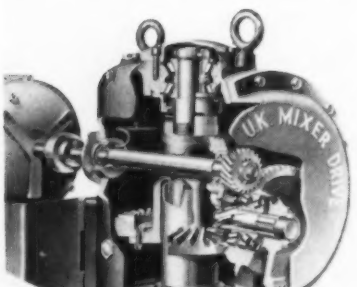
Following an extensive survey of requirements in the fluid mixing field, the newly formed UK Mixer Division of Stockdale Engineering has developed the first British range of spiral bevel agitator drives, designed specifically for fluid mixing applications.

There are five standard units in the range for both open and closed tank operation, and the drive assembly can be tailor made to meet highly specialized process requirements. The agitator shaft which transmits power from the

The tong head—of standard AERE design—is closed by a trigger mechanism, fitted with a fine adjustment for positive grip, and is rotated by means of a twist grip handle. A quick release trigger provides instantaneous release of the tong grip



prime mover to the impeller has been designed for maximum rigidity and minimum deflexion between bearings. The use of spiral bevel gears, generated by



The entire crown wheel bearing assembly may be lifted out as one unit. Rigid design and the use of spiral bevel and helical gears contributes to the virtually noiseless operation of the agitator

the Gleason technique, ensures high efficiency, long life and quiet operation. Variable mixing speeds are required in some processes and for this reason helical-spur 'pick-off' input change gears are fitted, and these can be changed without removing the drive or impeller shaft assembly from the vessel. Access is simply gained by removing the gear casing and no special tools are required. Only precision spline mounted gears are used.

A combined splash and pump-fed lubrication system provides a constant controlled supply of lubricant to the bearings and gears. Oil is retained in the gearbox by a Drywell to prevent it from running down the shaft into the product.

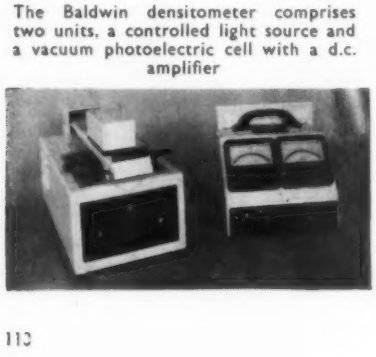
Tick **No 215** on reply card

HEALTH PROTECTION

film badge densitometer

Designed for rapid and accurate measurement of density of processed protection film badges, the new Baldwin instrument is claimed to measure low levels of density with a high degree of accuracy.

The Baldwin densitometer comprises two units, a controlled light source and a vacuum photoelectric cell with a d.c. amplifier



It may furthermore, be used as a precision general purpose densitometer.

The light unit is fed from a constant voltage transformer and has a coarse and a fine rheostat fitted for the control of level of illumination. The measuring table is of sufficient area to enable also large X-ray plates to be measured. The standard instrument is fitted with two viewing apertures, one $\frac{1}{8}$ in. dia and the other $\frac{1}{16}$ in. dia. With the large aperture, densities up to 6 can be easily read.

The output from the photocell is fed into a highly stable d.c. amplifier fitted with two inter-calibrated meters, one scaled to read over the density range zero to 2·0 and the other scaled to read zero to 0·5. A switch is provided to enable the user to change from one meter to the other. The d.c. amplifier is fitted with a range switch, which extends the scale of the standard meter by a factor of 3, thus leading to higher reading accuracy on high density.

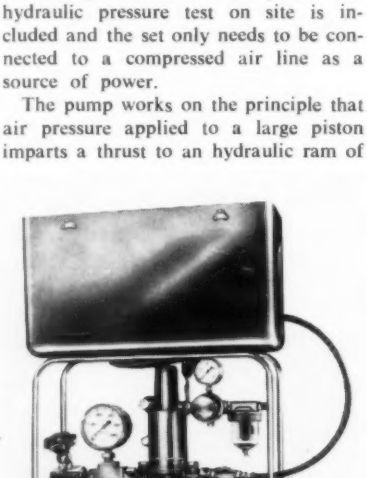
Tick **No 216** on reply card

HYDRAULIC TESTING

portable unit

The Madan portable hydraulic test set has been designed to meet the needs of insurance engineers, site engineers, and all whose work is essentially mobile. Everything needed to carry out an hydraulic pressure test on site is included and the set only needs to be connected to a compressed air line as a source of power.

The pump works on the principle that air pressure applied to a large piston imparts a thrust to an hydraulic ram of



The test set comprises an Airhydropump, air pressure regulator, air filter, hydraulic filter, air and hydraulic gauges, hydraulic stop valve, reservoir and six assorted adaptors for various B.S.P. connexions

smaller area. The set operates from an air supply of not more than 100 psi. An air pressure control valve is incorporated which enables all intermediate hydraulic pressures within the range of the pump to be accurately determined and which makes it completely safe for the operator to leave the item under test, as the desired test pressure is never exceeded.

The complete set is fitted in an attractive moulded glassfibre case which, when inverted, becomes a 5 gallon reservoir supplying the pump. The pump is the well known Madan *Junior Airhydropump,* which is available in six models covering pressures from 50 psi to 10,000 psi. All these are easily interchangeable in the test set.

Tick **No 217** on reply card

IN BRIEF

Air cylinders. Baldwin Instruments announce an improved speed regulator for their compressed air cylinders. Regulation is three times that of old model.

Tick **No 218** on reply card

Pressure transducer. Solartron are to manufacture Svenska Flygmotor AB's vibrating cylinder transducer. Natural frequency of element depends on applied pressure giving v.f. signal at constant voltage.

Tick **No 219** on reply card

E.M. Counters. Lancashire Dynamo are agents in UK for Hengstler electromagnetic counters types F43 and F43M2. Six digit indication, max rate 2400 counts/m. Already incorporated in LD counting equipment, they're now available separately.

Tick **No 220** on reply card

Welding set Single-operator, wheel-mounted model OT2 from GEC provides maximum intermittent output of 700 A, 80 V a.c. Continuous manual rating 650 A.

Tick **No 221** on reply card

Bare wire welding A new process of CO_2 shielded welding has been introduced by Philips Electrical.

Tick **No 222** on reply card

Plastic welding Goodburn Engineering have put on market a welding torch for polythene and p.v.c.

Tick **No 223** on reply card

Electric ovens From Hedin Ltd comes an improved version of their medium capacity models. Vertical airflow is used for floor loading.

Tick **No 224** on reply card

Crimping kit Tool from Erma Ltd cuts and strips wires, crimps on solderless terminals.

Tick **No 225** on reply card

Heaters Stabilag's new process allows a heating-element to be installed and a resin bond built round it. Predetermined shapes can be built up to $\frac{1}{16}$ in.

Tick **No 226** on reply card

Gears A wide range of instrument gears is obtainable from Pioneer Designs. They have split hubs, are attached to shaft by hub clamps, avoiding damage by grub-screws.

Tick **No 227** on reply card

INDUSTRIAL NEWSDESK

US air-ship combine

Lockheed Aircraft Corp has bought a controlling interest in the Puget Sound shipbuilding company. Lockheed have for some time been engaged on nuclear aircraft applications and ballistic missiles; Puget Sound is the largest shipbuilders and repairers on the west coast of the US. Mr Gross, Lockheed's chairman, has summed up this combination as 'with our planned investment in new additional facilities, we believe we may become eligible for a part in building atomic submarines, which apparently are destined to become the capital ships of the future'.

Vermiculite for FPs

The problem of disposal of radioactive waste becomes more acute with every nuclear reactor completed and increased fission products, particularly strontium, ruthenium and caesium, are produced.

There are a number of ways in which this waste may be disposed of but, apart from health considerations, it is important that this should be achieved as cheaply as possible. One method involves the use of ion exchange materials, the chief function of which is to absorb certain elements for which they have an affinity and to give up certain of their own constituent elements in exchange.

There are many materials both natural and synthetic which have these properties in greater or less degree, but crude vermiculite, a complex Mg, Fe, Al silicate, has been found to fill all the necessary requirements. These can be summarized as follows: the material must have a high cation exchange capacity; a rapid rate of exchange; good permeability, especially at high pH and sodium values; no breakdown of particles to colloidal dimensions which would pass out of the column thus raising the activity of the effluent; low cost.

At Harwell radioactive products are first treated chemically and then filtered through beds of crude vermiculite of pre-determined depth to give the maximum flow rate, consistent with the highest decontamination factor in both upward and downward flow columns. The process was described more fully in NUCLEAR POWER, March 1959 (p 110). An 18-in. thickness gave a decontamination factor of 600–1000 and the overall removal of elements was >97% Zr and Sr, 98% Ru, >98% Cs, and ~99·9% Ce.

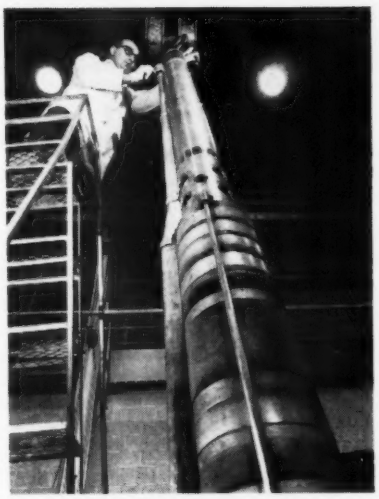
The Grade I crude vermiculite from the Palabora deposit in the North East Transvaal, supplied by Mandoval Ltd of London is being used.

Handyman assembles engines

For the past two months a new robot, Handyman, has been assembling nuclear-powered aero engines at the AEC's Idaho Falls test station. This unit built by the US General Electric has a thumb and forefinger on each arm and is capable of ten types of motion. Its big advantage over earlier robots is that it is able to clutch objects in its steel palms. Both hands have several dozen spring-loaded protruding buttons which may be depressed in varying degrees. Movements are transmitted electrically and mechanically from the operator's parallel controls. Three-dimensional, closed-circuit colour television enables the operator to see in proper perspective what he is doing.

US exports progress

The first US nuclear turbine unit has been exported to Belgium by Westinghouse Electric Corp. This unit will be installed in CEN establishment at Mol and will drive a generator to be built by Westinghouse's Belgian associates, Ateliers de Constructions Electriques de Charleroi. At full load the complete turbine unit will absorb 160,000 lb of steam per hour. Westinghouse are also completing the twelve 'flagpole' control rod mechanisms. The operating portion of the mechanism, contained in a 10 ft stainless steel tube, is in the form of a stack of magnetic coils which lift or lower the control rod through a series of steps to the required distance. The entire mechanism operates magnetically and is arranged to fail safe. The unit has an outside diameter of 7½ in. and is capable of lifting a control rod weighing 180 lb. High pressure coolant fluid is circulated over the outside of the stainless steel tube or 'can'.

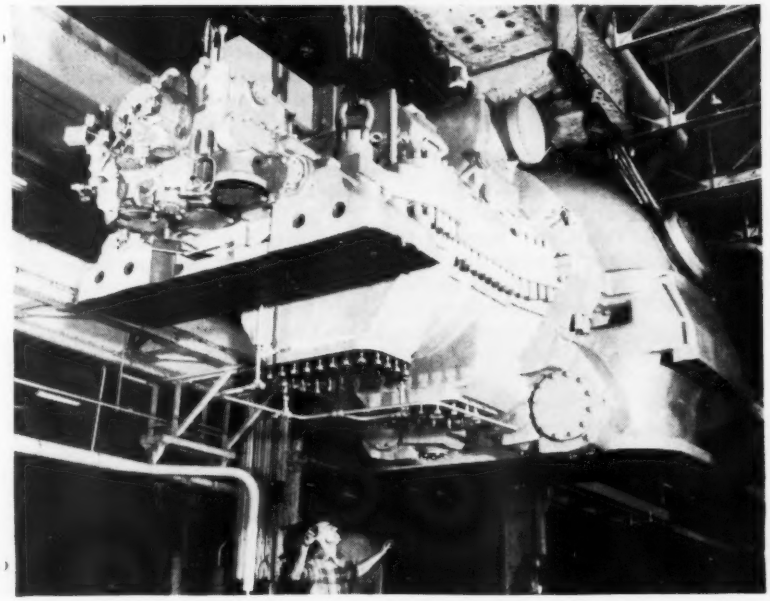


AMERICAN CONTROL FOR BR3—one of the twelve magnetically-operated Westinghouse control rod mechanisms for the CEN's pressurized water reactor BR3 being built at Mol, Belgium

Invisible exports

As a result of the understanding that has been reached between the British nuclear engineering companies and the insurance

SHIPPING THE FIRST US EXPORT NUCLEAR TURBINE—this unit, built by Westinghouse and weighing nearly fifty tons, will be installed in the 11,500 kW power plant of CEN's at Mol. The heat exchanger was shipped last August



companies it is expected that there will be a big rise in nuclear insurance market. The nuclear power stations at present under construction in the UK carry approximately £M5 third-party insurance each and the British equipment has therefore been 'hall-marked' in this way. It is anticipated that as similar equipment is supplied abroad the insurance will be placed in London.

Graphite used in aircraft

To meet the demand for large graphite honeycomb sections for the new chemically-fuelled US bomber, Union Carbide Corp of New York has developed production techniques to increase the size of stock blocks. The new bomber will use some 19,000 sq ft of honeycomb sections and blocks 110 in. in length are now being made. A number of such forms will be joined together to fabricate honeycomb panels of size previously not possible. Stainless steel skin surfaces are joined to the graphite honeycomb cores in high-temperature brazing furnaces. Single panels as large as 20 × 10 ft are being projected.

TWO YEARS' EXPANSION—recently the American Union Carbide produced a graphite block 110 in. long. Previously the maximum length was 84 in. and only two years ago the size, shown in the background, was 62 in. long

Mobile commissioning equipment

When testing or commissioning equipment at site delays are sometimes encountered due to lack of suitable facilities. To overcome the lack of de-ionized water John Thompson-Kennicott have made a self-contained portable de-ionization plant to produce chemically pure water. It is capable of treating between 1500 and 2000 gallons an hour of water drawn from any existing water supply and the output is the equivalent of, or better than triple distilled water and has a resistance of more than 2M ohms. The first job for this plant will be for the testing and initial operation of the sixteen heat exchangers at the Berkeley nuclear power station. Subsequently the unit will be available for use on any nuclear or thermal power station where water of high quality is required.

Air companies reorganize

Due to increased volume and greater technical complexity of the work undertaken the Carter Refrigeration & Air-conditioning Ltd and its subsidiary, the Midland Heating & Ventilation Co Ltd have reformed their organization. The group are engineers in air treatment and supply equipment for moving, cleaning, heating, cooling, humidifying and dehumidifying air. The holding company is Carter Thermal Industries Ltd and the operating companies are Carter Refrigeration Display Ltd, Carter Thermal Engineers Ltd, Carter Refrigeration & Airconditioning Ltd and the Midland Heating & Ventilation Co Ltd. Manufacturing and research facilities are being increased and work is progressing on installations for nuclear establishments.

Mainly education

● **OEEC Courses.** The European Nuclear Energy Agency of the OEEC is holding two international courses on nuclear energy for the teaching staffs of universities and higher technical colleges. One course will be held at AERE, Harwell, and the other will be at the Centre d'Etudes Nucléaires at Saclay. Both these courses will accept about 50 applicants and will run from July 20 to July 31. The latest advances in nuclear science and techniques will be studied and a certain amount of practical work will be done. In addition visits will be made to nuclear installations. The costs of these courses apart from travelling and living expenses will be borne by the Agency. Applications should be made to the OEEC European Nuclear Energy Agency, 38 Boulevard Suchet, Paris 16e.

● **Encouragement to train.** Thirty-two new grants totalling $316,717 have been made by the AEC to 31 American colleges and universities. These life science grants are to help in expanding training facilities for radiation biology and in the use of radioisotopes for agriculture, veterinary medicine, public health and biology. This is the sixth series of grants and brings the total number of such grants up to 152 since the programme was first initiated in 1957.

● **New premiums established.** The Council of the British Institution of Radio Engineers has established four additional premiums, two of which take into account the widening field of electronics. The Charles Babbage Premium is for a paper on the design or use of electronic computers and the Lord Rutherford Premium covers the increasing part played by electronics in control and instrumentation associated with nuclear physics and engineering. Both premiums have a value of 15 guineas.

● **Atoms at film festival.** Two films, 'Conquest of the Atom' and 'Metals of the Nuclear Age,' have been selected for showing at the second Festival of Films in the Service of Industry—this is being held at Harrogate from April 21 to 24. Sir John Cockcroft will be one of the principal speakers at the Festival.

● **AEA at Photo Fair.** A short teaching film 'Principles of Nuclear Fission' presented by the AEA in conjunction with the Education Foundation for Visual Aids (EFVA) will be shown on the EFVA stand at the Photo Fair—this international fair will be held at Olympia between May 11 and 16.

● **A new industrial exhibition.** Another industry has decided to hold a trade show—this is the Pneumatics and Hydraulics for Industry Exhibition and Convention and will be held at the Alexandra Palace from October 12 to 16. A feature of the Convention will be that the inaugural meeting of the Fluid Power Association will be held.

● **Induction heating in Yorkshire.** An exhibition and demonstration of induction heating and honing was given by Delapena & Son Ltd at the department of mechanical engineering, Sheffield University from April 6 to 10. This induction heating equipment has been or will be used during construction at Dounreay, Calder Hall, Springfields, Berkeley and Windscale.

CLEAN WATER ANYWHERE—during March the John Thompson-Kennicott Co completed a mobile de-ionization plant. Intended for testing and commissioning duties it will first be used at Berkeley nuclear power station

● **Course for seniors.** The next course for senior technical executives in industry on which places are available will be held from June 15 to 25 at the Harwell Reactor School.

● **Controlling reactors.** The second course on the Control and Instrumentation of reactors will be held at the Harwell Reactor School from July 7 to 17.

● **United Kingdom** The second course on the Control and Instrumentation of Reactors will be held at the Harwell Reactor School from July 7 to 17, 1959, inclusive. The course is primarily intended for those who have a direct interest in the control and instrumentation of nuclear reactors and it will be assumed that participants have some knowledge of the basic principles of the subject.

● **United Kingdom** The next course for senior technical executives in industry on which places are available will be held from June 15 to 25, 1959, at the Harwell Reactor School.

UK nuclear marine moves

During April there were further indications that British industry intends to take an active part in the future of nuclear ship propulsion. The Fairfield Shipbuilding & Engineering Co and Mitchell Engineering of Glasgow have entered into an agreement to work together on the study and development of nuclear marine propulsion. This agreement also covers design, manufacture and the sale of both main and auxiliary nuclear power units. This arrangement will bring together the combined knowledge of land-based nuclear power plants of Mitchells and their American cooperators, Combustion Engineering, with Fairfield's experience in shipbuilding and the fabrication of geared steam turbine installations.

Furthering these activities, Mr E. B. N. Mitchell and Cmdr A. Woodward, RN, a submarine expert, have visited Canada. This visit was to have exploratory talks with Canadian industrialists into the feasibility of operating submarine freighters in waters where extensive freezing-up occurs during the winter months—such as the Hudson Bay and Labrador coasts.

The initial design proposed to meet such requirements was the subject of a series of successful tank tests, carried out in cooperation with Saunders-Roe at Cowes. This preliminary design envisages a 50,000 ton submarine with a length of 600 ft and capable of cruising at 25 knots when submerged at a depth of 300 ft. The prototype of such a type of submarine could be built for less than £M20 and Mitchells are of the opinion that they could be ready for construction of it about 1967.

Like other nuclear projects, it is estimated that if three such submarines were built the unit cost would have then been reduced to at least fifty per cent of the cost of the prototype vessel.

Another, but more future nuclear application to marine propulsion has been included in the preliminary discussions covering the possibility of building a new British major vessel to succeed the Cunard's 'Queens.' While both John Browns and Cunards have observed that initially any such new vessel will be conventionally powered, replacement of this power unit by a nuclear power unit at a later date would be borne in mind; the design would be such that a changeover could be made without excessive internal re-arrangement.

In brief

● **Patents Freed.** A further 102 patents have been released by the AEC for public use. The Commission will grant non-exclusive, royalty-free licences. This brings the total to 1171 and is part of AEC's programme to make non-secret technical know-how generally available for use by industry.

● **Research Help.** Over a wide range of universities, institutions and industrial establishments, AEC allocated 440 research and development contracts during 1958. Of these 205 contracts were in the field of chemistry, 105 in metallurgy, 101 in physics and 19 in controlled thermonuclear research.

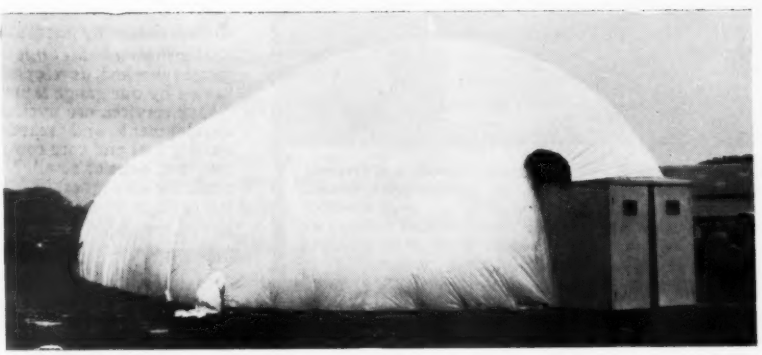
● **Deuce computer for Liverpool.** An English Electric electronic digital computer, Deuce Mark 1, has been ordered and is being installed at the University's Ashton Hall Mathematical Laboratories. Its work will include calculation of results of experiments of the nuclear physics department's synchro-cyclotron as well as calculations for outside organizations.

● **UK trainer at Hanover.** Vickers with the cooperation of the BOT are exhibiting a model of a 10 kW light water-moderated training, research and isotope reactor on the AEA stand at Hanover Fair at the end of April.

● **United States** Standard fuel elements, resulting in faster delivery, better service and lower prices has been planned by Sylvania-Corning Nuclear Corporation. Initially, four standard fuel element types suitable for use in a wide range of existing low-power recearch reactors will be made.

● **East Germany.** When Mr Khrushchev looked in at the recent Leipzig Fair he was presented with a fountain pen dosimeter on the Isotope Developments stand by sales manager Mr E. W. Jones. Later the firm received an order for a charging unit.

● **UK atomic TV tour.** Two senior members of Pye's made a tour of Can-



BEFORE AND AFTER—an inflatable airhouse made of synthetic fabric with Geon PVC has been introduced by The Gourock Ropework Co. Resembling a giant igloo, it is inflated by means of a low pressure fan which is left running and the airhouse remains erect because of the pressure differential between its inner and outer surfaces. It has been used at Hunterston and is suitable for providing temporary 'clean' areas on site. Various sizes are available and are made up from sections laced together prior to inflation. Cost of running the fan to maintain the pressure is about 1d. per hour

Requirement: Bond Integrity. Ultrasonic immersion testing equipment, designed specifically for our non-destructive testing use, checks bond integrity and soundness of fuel cladding.

Requirement: Dimensional Accuracy of Machined Parts down to 0.0001 Inch. Surface plate and electronic height gauge used to assure accurate measurement.

Requirement: Determine Sub Microgram Quantities of Fissionable U235 Surface Contamination (to 0.000000001 Gram). The largest internal chamber proportional counter ever made is successfully used to determine surface activity from fissionable materials on flat-plate type and ribbon type fuel elements.

The Inside Story

OF FUEL ELEMENT QUALITY CONTROL

at M&C Nuclear, Inc.

To assure the quality desired by reactor designers, we are experienced with every quality control test developed for the nuclear fuel industry. And we have created and used new tests and control equipment for our customers' special requirements. In addition, complete records are maintained for quality assurance of the final product.

Quality control services include:

Analytical Testing using emission spectrographic, x-ray spectrographic, chemical analysis and gas analysis testing equipment.

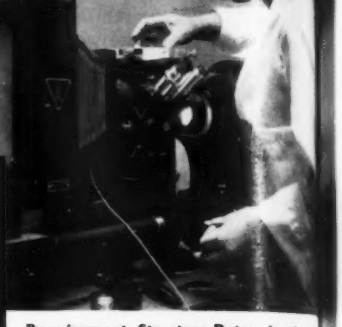
Metallurgical Testing using metallography, physical testing, and photographic techniques.

Non-destructive Testing including eddy current, ultrasonic, immersion ultrasonic, and helium leak test; as well as surface activity measurement and corrosion-tested sub-assembly surface checks by panoramic camera.

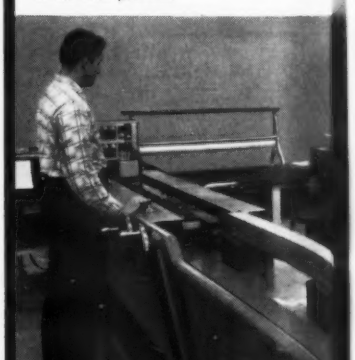
Dimensional Measurement using gauges checked, developed and maintained by our gauge laboratory.

Our services are available for the development and manufacture of quality fuel and core components for projects, large or small. New catalog available on request. Write:

Requirement: Structure Determination. metallographer determines and records structure, grain size, and bonding of meta graphic samples taken after each critical pl in the manufacture of fuel elements.



Requirement: Impurity Trace to 0.00000 Gram Accuracy. Optical spectrograph us in the quantitative and qualitative analysis alloying and trace elements in all metals us in the final product.



Requirement: Dimensional Accuracy Fuel Plate Assemblies to .001 Inch. Cust equipment to check and auto-record water ch nel spacing of fuel plate assemblies. Close mensional accuracy of the fuel plates is carr through to the fuel assembly to assure the qu ity of the finished product.

M&C NUCLEAR, INC.

P. O. BOX 898, ATTLEBORO, MASSACHUSETTS, U.S.A.

FUEL ELEMENTS. CORE COMPONENTS. COMPLETE CORES

Tick **No 81** on reply card for further details

adian and US atomic establishments demonstrating Pye television cameras which have been specially designed for gas-cooled and heavy water reactors. The equipment was also shown at the Ohio Atom Fair in April.

● **Closed circuit TV.** One of the most advanced systems of closed-circuit TV will be among the exhibits of EMI Electronics at the Hanover Trade Fair. Their stroboscope and hand and clothing monitor will also be shown.

● **Kent's tour UK.** During April and May the Kent mobile exhibition will be visiting 30 different places. The latest electronic developments and recorders will be shown.

● **Order for British filters.** Mancuna Engineering Ltd have been awarded a contract to supply filters for the Italian SIMEA nuclear power station under construction at Latina.

● **Vibration tests.** Environmental test laboratories have been set up by W. Bryan Savage Ltd for use by their customers. Equipment giving a range of thrusts between 250 and 3000 lb with automatic sweep are available.

● **EMI Monitor exported.** The recently introduced hand and clothing monitor made by EMI Electronics Ltd has aroused wide interest and already orders have been received from Canada, Israel and Australia as well as the UK.

● **Italy.** For the first time a 'Nuclear Energy for Peace' pavilion was included in the 37th International Samples Fair. This exhibition was held at Milan from April 12 to 27 inclusive; in addition to the Italian Research Council and organizations from France, Great Britain and USA, many industrial concerns exhibited.

● **Active identification.** US Radium Corp and Electronic Associates have developed a vehicle identification system for rail vehicles. By coding small active sources the system can be used for identifying vehicles either at rest or travelling at speeds up to 100 mph.

● **Site contractor for Hallam.** The AEC has appointed Peter Kiewit Sons' Co of Omaha to act as general contractor for the construction of the nuclear portion of the Hallam Nuclear Power Facility. The estimated value of the contract is approximately $M9.

● **New lab for 'Sunshine.'** Tracerlab Inc. reactor monitoring centre has opened a new laboratory to be devoted exclusively to the AEC 'Sunshine' analytical programme to study the effects of atomic weapons debris.

● **New design team.** The combination of design with functional application is the aim of the new company established at Bracknell, Berks. Two engineers and an industrial designer have formed Doughty Schofield Frank Sutton & Associates and work in hand includes the design of electronic equipment, industrial filters and heating systems.

● **New US office in Europe.** The Thompson-Ramo-Wooldridge Products Co, manufacturing computers, has opened an office in Paris. The growing number of customers in Europe for their computer control and data reduction systems has made it necessary to provide this sales engineering service.

● **New Elliott-Automation subsidiary.** The Swartwout Co Ltd has been formed by Elliott-Automation Ltd to manufacture and sell all the electronic control systems for the process industries, heating and ventilating and for nuclear and conventional power station instrumentation developed by The Swartwout Co of Cleveland, Ohio.

● **Licence for oxygen analyser.** The Distillers Co has granted a licence to Servomex Controls Ltd to manufacture and sell the DCL patented 'null balance' magnetic oxygen analyser.

● **Southern merger.** Two companies, Tyer & Co Ltd and P. A. M. Ltd, both subsidiaries of the Southern Areas Electric Corporation have been merged to provide a much improved production organization.

● **Name changed.** Davis & Thompson Ltd of Watford have changed their name to Datum Metal Products Ltd — this bears a closer relationship to its activities, the production of Datum instrument racks and cases.

● **New standards.** A new publication dealing with the mechanical testing at elevated temperatures is the British Standard Specification No 3082/1959 Part 1 'Determination of Proof Stress.' The material generally known as 'Silver Steel' is the subject of the revised British Specification No 140/1959 and includes the manufacturing, chemical composition and tolerance requirements.

CATALOGUES AND BULLETINS

Sceptre. Recent number of the Hilger Journal contains an article on the spectroscopic measurement of very high temperatures in Sceptre, by T. P. Hughes and R. V. Williams of AEI's Aldermaston Research Laboratories.
Tick **No 228** on reply card

Negretti instruments. Latest edition of Negretti & Zambra's general catalogue is in Norwegian.
Tick **No 229** on reply card

Brakes. Catalogue from Lancashire Dynamo & Crypto describes and illustrates the uses in various industries of their a.c. and d.c. brakes.
Tick **No 230** on reply card

Miniature relay. Advance information has been issued of a new Ericsson a.c. chopper relay.
Tick **No 231** on reply card

SS vessels. Brochure illustrating custom-tailored and off-the-shelf equipment made by Stainless Steel Vessels has been issued.
Tick **No 232** on reply card

Fellowships. The International Atomic Energy Agency have issued a brochure giving details of fellowships available.
Tick **No 233** on reply card

Protective clothing. Catalogue from Siebe Gorman gives full range of company's suits, hoods, helmets, gloves, respirators etc.
Tick **No 234** on reply card

Photomultipliers. Colour brochure from Mullard Ltd gives full technical specifications of the new AVP and UVP tubes.
Tick **No 235** on reply card

Servo. Brochure from Feedback Ltd (D102-1) describes components developed in connexion with Servomex Controls Ltd.
Tick **No 236** on reply card

Tantalum. Four-page folder from the National Research Corporation gives details of their products and applications to the electronic, nuclear, chemical and missile industry.
Tick **No 237** on reply card

Zirconium. ICI have produced a booklet entitled 'Zirconium Weight Tables.' Weights are given for zirconium plate and sheet, bar, wire and tube.
Tick **No 238** on reply card

Pipe clip. Nobol boltless pipe clip made by Charlton, Weddle & Co Ltd can be supplied in any metal, including aluminium alloy, if required. Leaflet describes.
Tick **No 239** on reply card

Swiss machine tools. Details of plate bending, trimming and rolling machinery etc made by the Swiss firms of Haemmerle and Haeusler are supplied in leaflets from UK, Commonwealth and Scandinavian distributors Haemmerle (London) Ltd.
Tick **No 240** on reply card

Aluminium cables. Well produced technical book with illustrations and data tables from Aluminium Union Ltd describes the use of aluminium for insulated cables.
Tick **No. 241** on reply card

Expansion, contraction and lateral movement of pipe work under extreme conditions of temperature and pressure is no problem to the engineer who has been wise enough to contact and consult TEDDINGTON technicians.

Teddington Bellows Expansion Joint cylinders are butt-welded from highly finished cold rolled stainless steel sheet. Convolutions are introduced to give the bellows their characteristic flexibility. Nuclear, chemical, marine and gas engineers acknowledge their efficiency and superiority over many older forms of expansion joint. Wherever pipework is subjected to vibration or movement in any direction, a Teddington Bellows with a suitable end-fitting will solve the problem.

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EXPANSION JOINTS

TEDDINGTON AIRCRAFT CONTROLS LIMITED, (*Industrial Bellows Division*)
Ammanford, Carmarthenshire. Tel: Ammanford 2255

They said...

points from papers, speeches, conferences

Planning in the USSR

At the annual general meeting of the USSR Academy of Sciences in Moscow on March 26, Alexander Nesmeyanov, the President, expressed confidence that notable progress would be made in the field of controlled thermonuclear reactions. He pointed out that the main lines of development for Soviet science under the Seven-Year-Plan (1959-65) would be the theory and practice of the automation of production processes, the mastery of controlled thermonulear reactions, transistor technology, chemical synthesis and the elucidation of the physical and chemical laws governing the phenomena of life. The president said that in the period between the 20th and 21st Congresses of the Communist Party, the Academy had been supplemented by 63 research establishments, including 48 institutes. The effort that the USSR is putting into this work is indicated by the fact that some 51,000 research workers are now engaged on this programme.

Laboratory earthquakes

To make sure that every possible aspect of earthquake hazard in relation to nuclear power stations has been covered the Japanese Atomic Power Company appointed a special committee under a leading Japanese seismic expert. This was stated by Mr Tamaki Ipponmatsu, vice president of the JAPCo at a reception in London on April 9 to celebrate the issue of a letter of intent to GEC for a 150 MW gas-cooled power station at Tokai Mura.

Mr Ipponmatsu said the main problem was to find out whether a graphite pile would behave as one body or whether it would collapse during an earthquake. They therefore built a $\frac{1}{4}$-scale dynamically similar model of the GEC core and mounted it on a vibration table. Weighing 40 tons, this apparatus is the largest of its kind in the world and can give acceleration of 1*g* horizontal and 0·5 *g* vertical. The results of experiments showed that the pile, weighing 1500 tons, should in fact behave as a rigid body.

A novel safety device is being incorporated in the reactor. Mr K. J. Wootton said that if there were a seismic disturbance sufficiently severe to make a scram advisable a system was being developed which would release a number of boron steel balls of about 1 in. dia into special channels in the graphite structure. It will probably be actuated by a seismic switch. While this is more complicated than straightforward liquid borax or boracic acid injection such a drastic measure would probably write off the reactor for good whereas the balls are of course perfectly simple to remove once the shock has passed. The GEC scram system is designed to operate even if the reactor tips to 45 degrees.

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UK need never go short

Of all the fuel industries electricity is the best situated, said Mr Philip Honey of the Electrical Development Association on April 3 when addressing the Institute of Quarrying's Fourth course at the Ashorne Hill Centre. This, he stated, was because of electricity's ability to use low-grade coal in its power stations. Nevertheless today's sufficiency of low-grade coal would eventually become inadequate to meet the ever-increasing demand for electricity even if ways and means were found to convert low-grade coal into gas or some kind of smokeless solid fuel.

The future of fuel and power would be a dismal story, he said—ever-decreasing supplies in the face of an increased demand—were it not for the prospect of nuclear energy. While for many years it could only make a small contribution to the country's electrical requirements, by 1965-66 there would be some twelve to fifteen nuclear power stations, generating a total of between 5 and 6 million kilowatts. The magnitude of this amount could be compared with the present demand which on one cold day in January this year reached a record of 20 million kilowatts.

By 1965 this peak demand may well have increased to 36 million kilowatts or even more. As time went on more and more power would come from nuclear stations until by 1980 the majority of electricity production would come from the atom. Mr Honey said: 'It was reassuring to know that with the growing use of electricity Britain need never go short of power in the future.'

Profits appearing

On the occasion of the annual report last March of the US Babcock & Wilcox Mr Nielsen, the President, said that some parts of the company's nuclear work 'have begun to show a modest profit' while its overall atomic operations 'continue at a loss, although less than in previous years.' Reviewing the US nuclear engineering industry generally Mr Nielsen stated that a number of companies have curtailed their operations in the atomic energy field 'after realistic reappraisals' but that B & W's activities 'continue to grow because they are logical developments of our basic business.' These indications of the industry's difficulties in recovering the large initial development and research funds are made very clear and a rather similar state of affairs exist in the British nuclear engineering industry—many more projects will have to be completed before the companies break even.

The opinions expressed by Mr Nielsen were echoed by Mr S. S. Auchincloss, the President of Tracerlab, in his 1958 annual report issued at the end of last March. This group cut back its losses during the past year by 80% to only some £93,000. His solution does not follow the same pattern but to develop new equipment which will create its own demand. He said 'to maintain our leadership in the nuclear and X-ray field, we must step up the development which leads to new products which are essential for us to achieve and hold commercial leadership.' Referring to the beginning of this policy, Mr Auchincloss stated that from 1957 his company's aim was to sell only those products from which a worthwhile profit accrued.

This policy will be implemented by making special efforts to develop more automated equipment for nuclear instrumentation. To meet the shortage of technical people to operate nuclear equipment he said that the existing working force should be freed for more responsible work; that automatic data processing equipment should 'eliminate the tedious work of manual data handling which now takes so many hours of the nuclear technicians' time!'

NAMES IN THE NEWS

Mr W. H. McFadzean, chairman and managing director of British Insulated Callender's Cables has been elected president of the Federation of British Industries for 1959–60.

Mr M. H. Shepheard has been appointed architect in the chief design and construction engineer's department of the CEGB.

Monsieur E. J. Solvay of Brussels will succeed Sir Robert Robinson as president of the Society of Chemical Industry in July this year.

Mr E. G. Wakeling has joined Advance Components as general manager. He was previously manager of Elliott Bros servo division.

Sir Charles Westlake, Mr John Black and Mr H. O. Houchen have joined the board of Avo Ltd following the resignations of Mrs E. Rawlings, Mrs M. Brook and Mrs I. E. Widdows. Avo Ltd recently became a member of the Metal Industries group.

Mr I. W. Trench will occupy Klockner Moeller's newly created post as sales engineer for the Scottish area.

Mr W. G. Thomas of Bailey Meters & Controls and Mr V. D. MacLachlan have been elected president and chairman respectively of BIMCAM (The British Measuring & Control Apparatus Manufacturers' Association).

Mr F. J. Fagard has been made managing director of Power Jacks Ltd.

Mr L. Rumley (sales director of Electro-Hydraulics Ltd and Conveyancer Fork Trucks Ltd) will direct the newly established industrial hydraulic sales department of Electro-Hydraulics Ltd.

Dr S. Lawroski, director of Argonne's chemical engineering division, led a team of Argonne scientists who visited nuclear energy establishments in Great Britain and France during April.

Mr Titus Leclair has been elected chairman of the board of directors of America's Internuclear Company.

Mr G. B. R. Feilden has been elected a Fellow of the Royal Society. Mr Feilden is engineering director of Ruston & Hornsby Ltd.

Mr D. M. Cherry has been appointed transmission plant and equipment design engineer at the headquarters of the CEGB.

Mr C. A. Henderson, who joined Eutectic Welding Alloys in 1958 as general manager, has now been appointed managing director of the company.

Mr F. R. McKears becomes the new editor of *Torch,* British Oxygen's quarterly technical publication. Mr McKears was previously advertising manager at Elliott Brothers (London) Ltd.

Mr J. K. Thornley and Mr P. Lawrence have been appointed by Baldwin Instruments to be technical representatives for the North of England and Midlands respectively.

Mr J. S. Crick has joined Plessey Nucleonics Ltd as sales manager. Mr G. V. Hough, previously commercial manager, becomes advanced projects manager.

Mr J. S. Brough has been appointed by Humphreys & Glasgow Ltd to be technical director and general manager. He will act as deputy to Mr G. G. Farthing deputy chairman and managing director.

Mr A. A. Haining has become sales manager of Exactor Ltd. He was formerly deputy sales manager of Sigmund Pumps Ltd.

Dr B. Blumenthal, an associate metallurgist at Argonne will have a year's leave of absence in order to help Belgium with their plutonium research and development.

Mr N. T. Burgess has joined the research and development department of the CEGB as welding metallurgist. He was formerly with the Aluminium Development Association.

Mr G. Laing has been appointed to the board of Miller Insulation and Engineering Ltd.

W. H. McFADZEAN

C. A. HENDERSON

G. B. R. FEILDEN

J. S. BROUGH

OBITUARY

Sir Ashley S. Ward, president of Thos. W. Ward Ltd, on March 26, at the age of 81.

Mr J. L. P. Brodie, engineering director of The de Havilland Engine Co, on March 23. He was 59.

MAY DIARY

ICE Institution of Civil Engineers. IMechE Institution of Mechanical Engineers. IEE Institution of Electrical Engineers. IChemE Institution of Chemical Engineers. IP Institute of Physics. PS Physical Society. SCI Society of Chemical Industry. IM Institute of Metals. IMet Institution of Metallurgists. IMM Institution of Mining and Metallurgy. IPE Incorporated Plant Engineers. SIT Society of Instrument Technology. BritIRE British Institution of Radio Engineers. RSH Royal Society of Health. IR Institute of Refrigeration.

FRIDAY 1

CHELTENHAM BritIRE Transistor amplifiers *F. Butler* 7.00 North Gloucestershire Technical College

THURSDAY 7

SHEFFIELD IMechE AGM followed by Recent developments in nuclear engineering *A. T. Bowden* 6.30 Grand Hotel

STOKE ON TRENT IEE AGM followed by a review of work towards nuclear energy from controlled thermonuclear reaction *D. W. Fry* 7.00 Technical College

MONDAY 11—WEDNESDAY 13

LONDON IChemE Symposium on instrumentation and computation in process development and plant design Central Hall, Westminster Information from the Secretary, IChemE

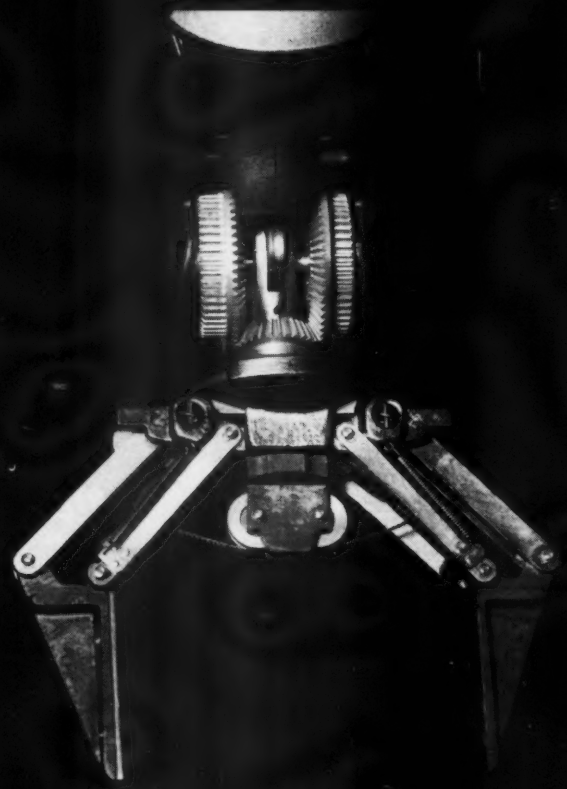
TUESDAY 12

LONDON SCI Fuel economy in chemical works *W. Quick* 6.00 at the Society's headquarters

WEDNESDAY 13

LONDON BritIRE Improving communication techniques—what have engineers to learn from information theory *Prof D. Gabor* 6.30 Society of Hygiene and Tropical Medicine, Gower St

LONDON SIT A multipoint digital strain-gauge recorder *J. R. Sturgeon* 6.00 Manson House, Portland Place



Manipulators

The manipulators used at atomic establishments have to operate under exacting conditions. They are constructed of stainless steel and Kanigen plated aluminium and the plate serves two functions. It resists corrosion and, because of the smoothness of the finish, it also assists in decontamination of the component parts from radio-active material; and the combination of stainless steel and Kanigen plated aluminium reduces the electro potential difference between the component parts. These manipulators, manufactured by Savage & Parsons Ltd., are supplied to users all over the world. Kanigen is used on the aluminium parts of the Tong End assembly and the Master Hand assembly.

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Book Reviews

Nuclear classic

The Physical Theory of Neutron Chain Reactors by A. M. Weinberg and E. P. Wigner Chicago 1958: University of Chicago Press (UK: Cambridge University Press) 801 pp Price 112s 6d

Two distinguished authors write a book of 800 pages. It must be good: the interesting questions are, is it useful, and will it be used? There is no doubt that Weinberg and Wigner's book will be indispensable to most reactor physicists for many years to come.

The book is in four parts: nuclear physics, transport theory, general reactor theory, and heterogeneous reactors. The first contains an invaluable introduction to neutron cross sections, resonance reactions, fission processes and the shell structure of the nucleus. As the authors point out, 'reactor theorists nowadays have less sophistication in nuclear physics, at least relative to the available knowledge, than did the originators of the theory.' The section on nuclear physics, and the discussion of the physical meaning behind the mathematical approximations given in later sections, should do much to make cognoscenti of us all. There are occasional lapses—for instance I found the description of the optical model of the nucleus rather obscure—but this is more than balanced by the general excellence of presentation.

The scope of the book is so comprehensive that we can only illustrate its various approaches by considering a few isolated topics. The theory of slowing down is treated in great detail; exact solutions, P_1 approximation, age theory, effect of resonances, Selengat Goertzel method, and so on, are all lucidly described and effectively assessed. The chapter on static control rods starts with simple examples to illustrate the physics, discusses the usual one and two group theories of central, off-central and arrays of rods, considers the effects of shadowing and of extrapolation distances, and includes a discussion of some experimental results. The effective absorption and uniform poisoning methods, which are used in computer codes, might have been mentioned.

The section on thermal neutrons provides an excellent introduction to current ideas on the subject. The problem is outlined, the complicating factors are mentioned, experimental results are discussed and a summary of certain approximate and exact theories is given. One feels that the isotropic part of the scattering law for a monatomic gas could have been derived in the text, especially in view of the detailed discussion which the elastic scattering of epithermal neutrons receives. The references in this section are particularly well chosen.

The chapter on perturbation theory is a model of didactic writing. The first example studied is the perturbing effect of a single extra neutron introduced into a one energy group reactor: this provides a striking illustration of the significance of the importance function, around which the rest of the chapter develops. Individual topics such as Doppler broadening, synthetic kernels, B_L approximation to the Boltzmann equation, to mention a few at random, can be found in the general index, and reference to the text reveals a brief but elegant account of these subjects.

The authors warn in their preface that they 'have done less than justice to the many elegant machine-computing techniques which are now in vogue in many reactor centres, especially in the United States.' It is true that the few comments they make about numerical methods are wrong. For example, current methods of integrating the multigroup equations are always stable, contrary to the statement on page 520. On the other hand, it is only a conjunction with exceptional insight into the physics of reactors, such as this book displays, that machine computational methods have any chance of real success.

A. Hassitt

First of many

Production of Nuclear Materials and Isotopes Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Volume 4 London 1958: Her Majesty's Stationery Office 631 pp Price £5 18s

One cannot judge the 1958 Geneva material as just another book. It is raw material—homogenized to a certain extent by skilful editing—but still a collection of original work with no overall processing to give comparisons and contrasts. As such it is perhaps even more valuable than an edited-down version, for every individual specialist is probably looking for those little details which so easily get lost in an editor's effort to avoid duplication and overlap. There is room of course for both approaches to Geneva but for the specialist there can be no substitute for the tablets of the Law as handed down on the shores of Lac Leman in September 1958.

The contents of this particular volume—only one of a total of 33—are 88 papers on the following subjects: purification of uranium concentrates, preparation of UF_4 and UF_6, reduction of UF_6, preparation of thorium compounds, graphite, zirconium, beryllium and other materials such as rare earths, theory and practice of isotope separation by all known methods including systems for deuterium, lithium, boron and oxygen. A feature of great interest in the Geneva proceedings, as for the 1955 set, is the almost verbatim discussions following each session.

The Geneva proceedings are undoubtedly the most important single source of nuclear knowhow but unfortunately it is extremely difficult to find one's way around. The last volume of the 33 promised is to be an index but the index for the 1955 proceedings was published only a month before the 1958 Conference. No doubt the compilation of a really comprehensive index is an immense task of bibliography but it is essential if the full benefit of the Conference is to be obtained. What would help greatly—and it could be done with comparatively little effort—would be to issue, as a purely interim measure, a simple 3-way index of paper numbers, authors and titles. At present, unless you know the number of the paper the task of finding its title and author is formidable. Could I appeal to the UN to make life easier by doing this right away?

C.D.

From theory to practice

The Industrial Cooling Tower by K. K. McKelvey and M. Brooke London 1959: Van Nostrand 429 pp Price 90s

The design of cooling towers and the drawing up of a thermal specification for a cooling water duty can be a very complicated and involved subject, as the authors rightly state in the preface. They have, however, produced an excellent book that should be an asset to the engineer, student, and technical library. The comprehensive data on fundamental terminology and psychrometry available in the opening chapters can be used as a reference for theoretical design and estimating purposes.

The many and varied charts, diagrams and illustrations refer to cooling towers of all types and designs, giving much theoretical information on cooling tower aspects ranging from packings, packing materials, drift eliminator efficiencies, water treatment, and carry over to practical performance and economic tower choice.

It is the chapters dealing with the

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economics of cooling towers that one must read carefully and thoroughly before arriving at any conclusions. As an example one chapter compares, unfavourably, a mechanical draught cooling tower installation consisting of 13, or alternatively 16 cells, each 32 feet square with a natural draught tower. No experienced mechanical cooling tower designer would propose the installation of 13 or 16 such small tower cells for one particular duty.

Also the relative costs of suitable timbers for cooling towers and materials and labour for concrete structures vary widely throughout the world. These costs have a definite bearing on cooling tower economics apart from climatic, and particularly functional, conditions which are all-important.

For process heat dissipation with peak heat loading during the hottest part of the day (mid-day), as opposed to steam condensing for power generation stations with peak loadings occurring morning and evening, towers must be designed to cope with the most arduous cooling conditions. A natural draught cooling tower designed for peak loading would be standing idle for most of the time whereas with mechanical draught towers, usually initially less costly, considerable power economy can be achieved outside peak temperature conditions.

Finally, the chapters dealing with cooling tower materials make one significant omission: namely, plastics for packings. Plastic materials, inert and non-corrosive have been used for packings for some years in the USA and are now available for all types of towers in the UK.

C. E. Mollison

Galactic star

The Theory and Design of Magnetic Amplifiers by E. H. Frost-Smith London 1958: Chapman & Hall 506 pp Price £3 15s

The past ten years have seen a minor galaxy of articles and papers on magnetic amplifiers, but books on the subject are few. This timely volume by Dr Frost-Smith will be welcomed by students and by many engaged in design or application of magnetic amplifiers.

The book contains a thorough exposition of many types of magnetic amplifier now in common use. The author covers the field from the early transductor to modern half-cycle response amplifiers. Medium and low-power amplifiers dominate; little mention is made of high-power amplifiers. Circuit theory is developed with a minimum of mathematics and in easy stages starting with the early transductor.

Dr Frost-Smith's experience with closed loop control systems is reflected in the thoroughness with which he handles such complex features as transient and frequency response. Also he explains in detail many other facets of magnetic amplifier behaviour that tend to confound the unwary.

The construction and design of magnetic amplifiers are fully considered, and designs for several typical amplifiers are given. These show that, although design calculations are not over-difficult, a wide knowledge of amplifier behaviour is essential. The book concludes with a short review of applications.

The appearance of Dr Frost-Smith's book, as the first in a new series on automatic control engineering, gives emphasis to the widely acknowledged importance of magnetic amplifiers in modern control systems.

R. D. Pettit

This review originally appeared in CONTROL

In brief

Prospects for Nuclear Power London 1959: Political and Economic Planning Price 2s 6d.

Prospects for British exports of nuclear reactors and equipment depend not only on the competitive ability of British firms but also on the political agreements that the Government is able to make. Such is the main conclusion of this excellent little pamphlet. It continues —' Marketing nuclear reactors is not purely a commercial undertaking but also involves international politics. Unless this is clearly understood, British chances of building up an export trade will be small.' With this, most of us would agree.

C. D.

British Instruments Directory and Buyers' Guide London 1958: SIMA and United Science Press 640 pp Price £2 2s.

Replacing the old *British Scientific Instruments* published by the Scientific Instrument Manufacturers' Association and the *Instrument Directory and Buyers' Guide*, this is a completely new publication of about 640 pages—about half of which are firms' announcements and advertisements. There is a classified products section of about 2500 different kinds of instrument and an instrumentation glossary in French, German and Spanish. Eleven other manufacturers' associations have collaborated with SIMA in the compilation.

The Design of Physics Research Laboratories. London 1959: Chapman & Hall for the Institute of Physics Price 21s

In November 1957 the Institute of Physics, London and Home Counties Branch held a symposium on this subject which was attended by 400 architects, physicists and others interested in the design of research laboratories. So many requests were received for reprints that the complete papers and discussions have now been published in book form.

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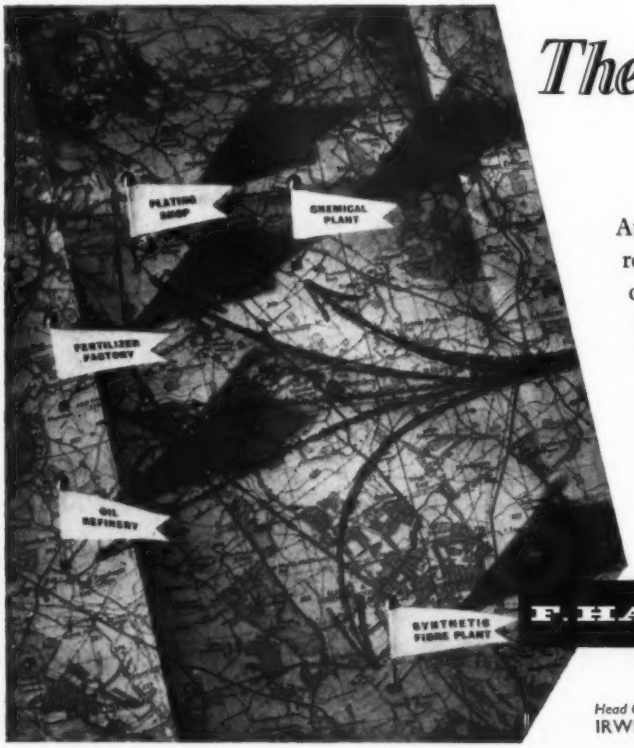

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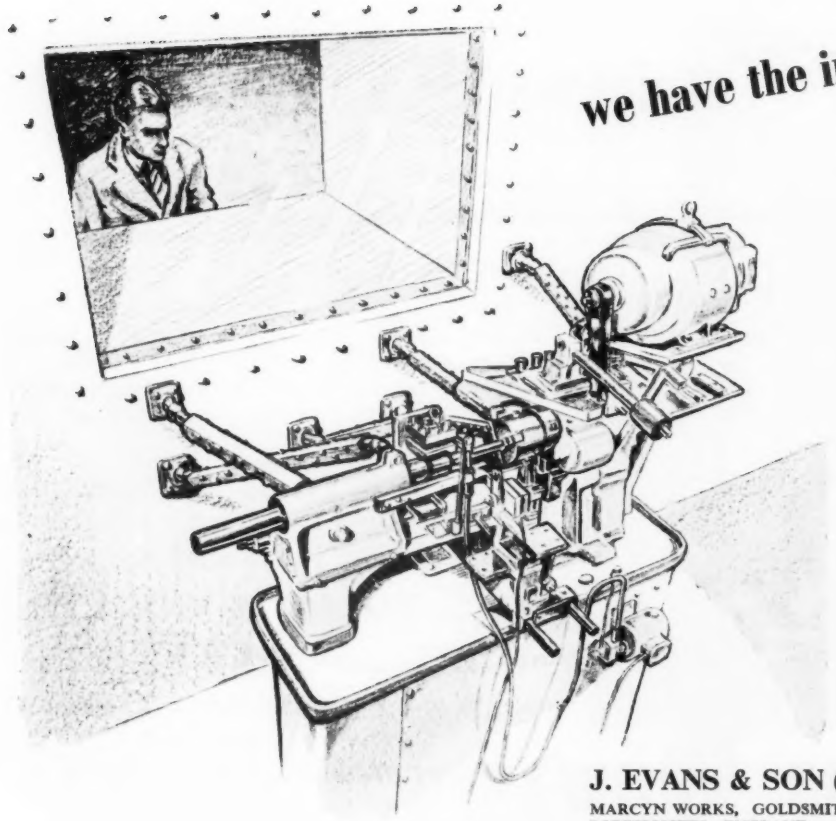

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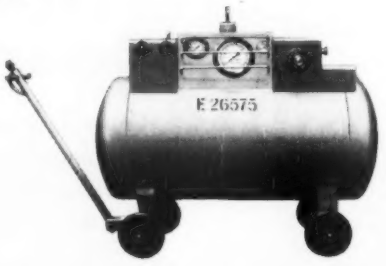

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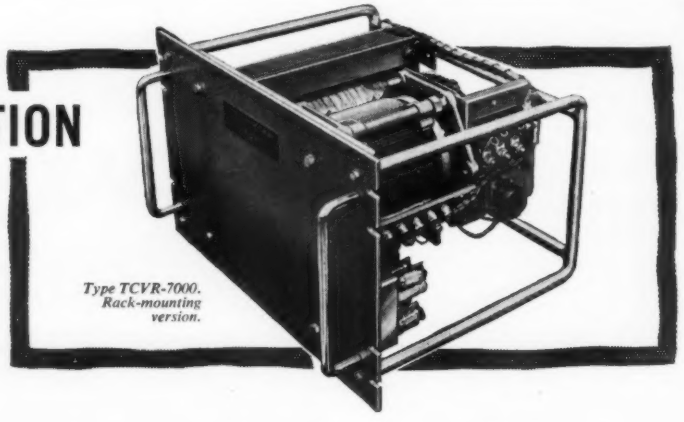

Type TCVR-7000. Rack-mounting version.

Other products of Claude Lyons Ltd. Stabiliser Division

BMVR: Motor-driven laboratory and industrial regulators ranging from 1·6 to 29 kVA single-phase, and 4·8 to 87 kVA three-phase. Constancy of output normally ± 0·5% from no-load to full-load. No distortion. Speed of correction 1 Volt/Sec. A great variety of models, standard, tropical and militarised, for all applications.

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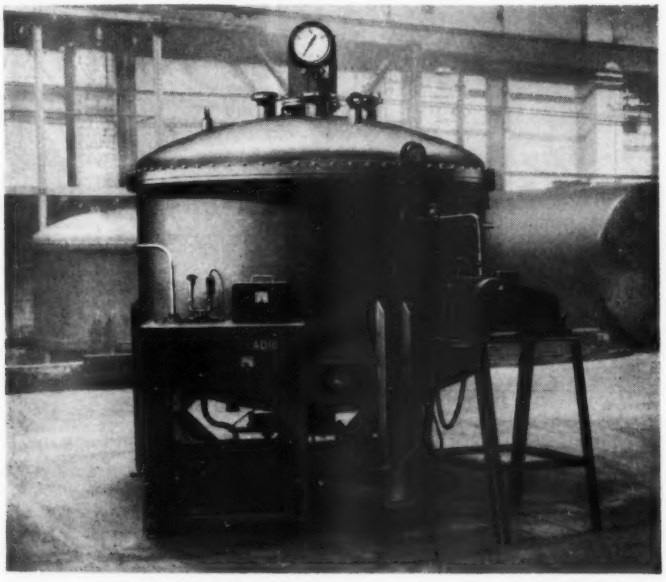

Illustrated on left:
2 tons capacity Liquid Oxygen Storage Tank. Inner vessel $\frac{1}{4}$" × $\frac{1}{2}$" thick 18/8 Ti Stainless Steel; Jacket $\frac{3}{8}$" × $\frac{1}{2}$" thick Mild Steel. Jacket space filled with Expanded Perlite. Inner vessel tested 100 p.s.i. Jacket tested 30 p.s.i. for ·01 mm Hg. working vacuum. The illustration shows the vessel set up for vacuum tests for Air Products (G.B.) Limited for the Admiralty.

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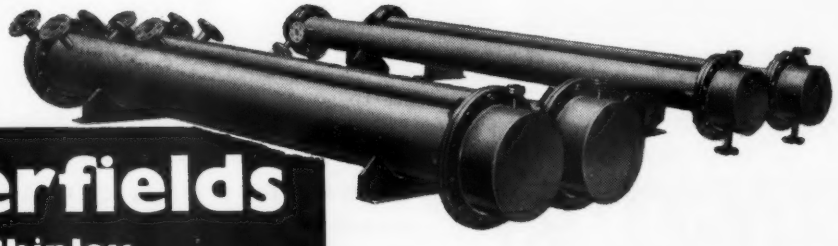

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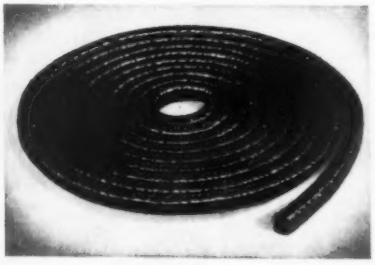

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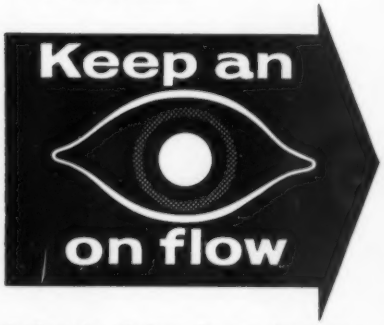
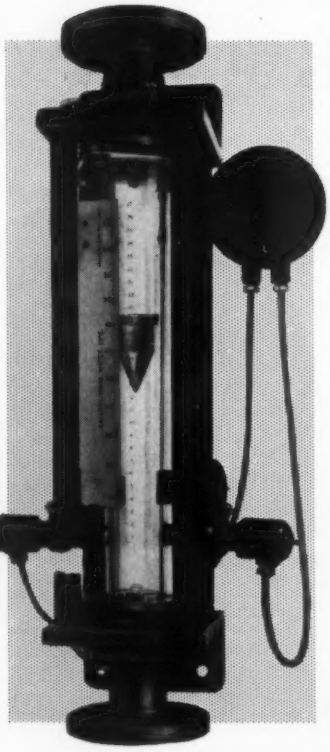
★ A positive signal to any remote instrument.
★ Can operate either a simple alarm or a digital counting mechanism.
★ Will signal high or low degrees of flow rate.
★ 2 alarms can be used to provide high and low flow alarm.

Keep an  **on flow**

★ One size of alarm fits any size of type 907 or 914 frame.
★ Can be fitted to instruments already installed.



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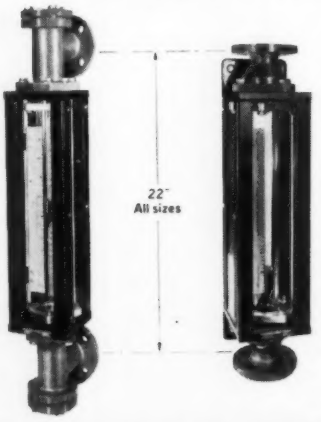

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In step with the vast building project, Henley cables* are being installed in Reactor buildings, Turbine Hall, Substations and other associated works as the civil work proceeds. Cabling for the first Reactor is now complete and for Reactors 2 and 3 is well in hand.

(A) TURBINE HALL. *Cable installation in Turbine Hall Cable Annexe.*
(B) REACTOR BUILDING. *General view of REACTOR building.*
AERIAL VIEW OF SITE. *Aerial view showing progress at Chapelcross. In the picture are cooling towers, reactors, turbine hall and administration buildings.*

Aerial photograph by permission of Mitchell Construction Company
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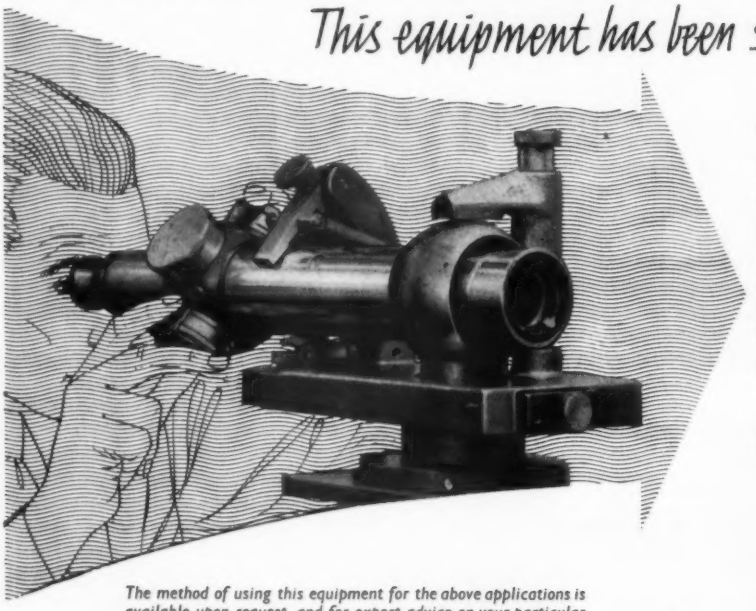

. . . the United Kingdom Atomic Engineering Research Establishment in the construction of Experimental Nuclear Reactors and the associated Projects ZETA, BEPO, ZEUS, ZEPHYR, DIDO and PLUTO. Also used by the leading manufacturing groups in the construction of Nuclear Power Stations, of the Power Supply Plan in Great Britain.

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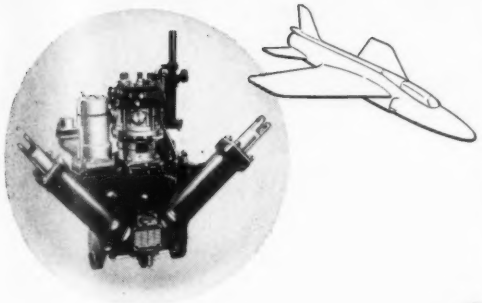

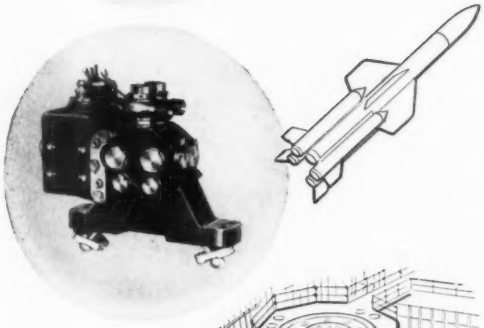

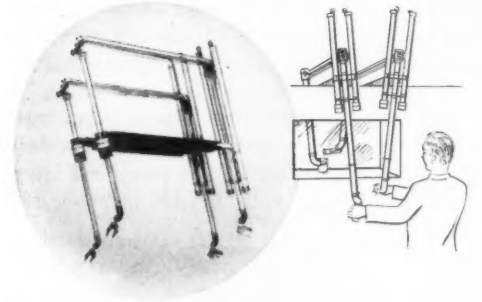

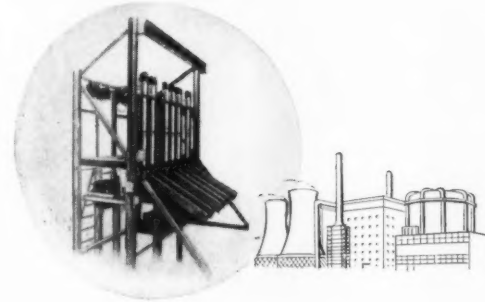

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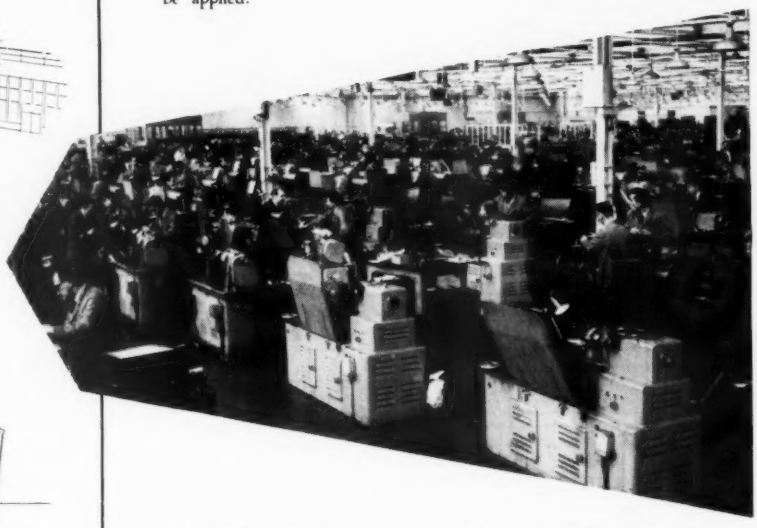

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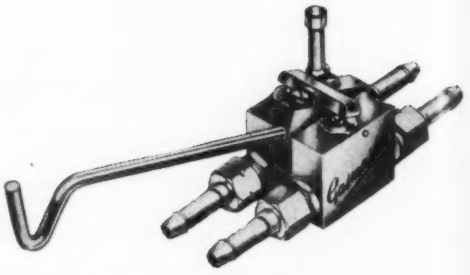

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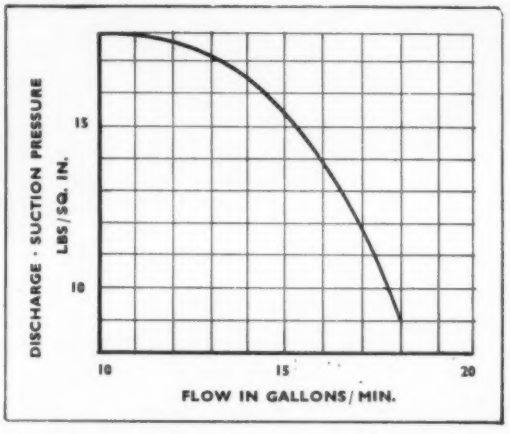

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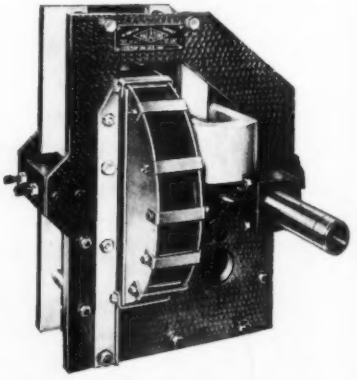

PROOF OF PALATINE PRECISION . . . 3

This performance curve shows the pump operating with sodium potassium at 350 C., a circuit pressure of 30 p.s.i. and running at 210 volts.

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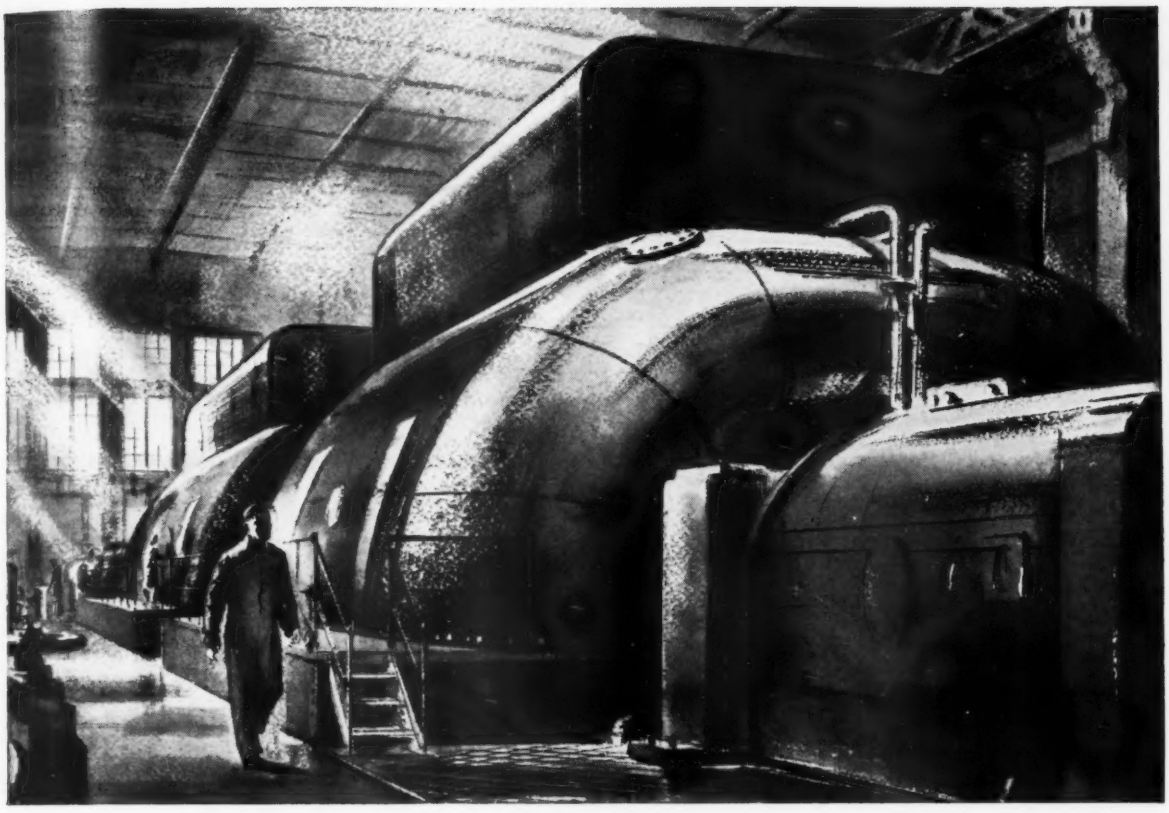
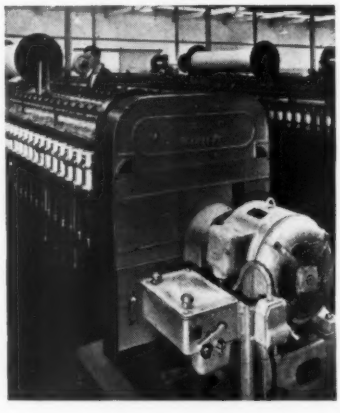


The world's largest Generators will help to fill the demand for still more power

Progress in the development of nuclear energy for generating electricity is still making front-page news —and rightly so. Spectacular advances are continually being made. Less publicised, though in their own field no less outstanding, are recent developments in the design of "conventional" generating plant. The turbo-alternator illustrated, for instance, is a 550,000 kilowatt unit—twice the capacity of the next largest generator now on order for the Central Electricity Generating Board. This machine has been designed for the projected new power station at Thorpe Marsh. For Blythe 'B', another new station, 275,000 kilowatt in-line units are on order. These sets will be served by unit boilers and will operate at steam conditions of 2350 lb. per sq. in. and 1050°F, with reheat to 1000°F.

Nuclear power stations will play an increasingly important part in meeting the doubled demand for electricity forecast for the next ten years. Construction work is progressing rapidly at the sites of the Board's first three nuclear power stations, at Bradwell, Berkeley and Hinkley Point. The aggregate capacity of these stations will be not less than 1,100,000 kilowatts; and by 1966/7 some 5 to 6 million kilowatts of nuclear-generated electric power will be available.



Though these are projects which will not be completed for some time, the work of the Central Electricity Generating Board is playing an important part in today's fight against inflation. Power stations are being built now at an overall cost no greater than in 1948—£50 per kilowatt installed. And, although the output capacity of the industry has doubled since 1948, the increase in manpower is only about one-third.

By providing today for the power we shall need in years to come, the Central Electricity Generating Board is building a secure foundation for our future prosperity.

THE CENTRAL ELECTRICITY GENERATING BOARD

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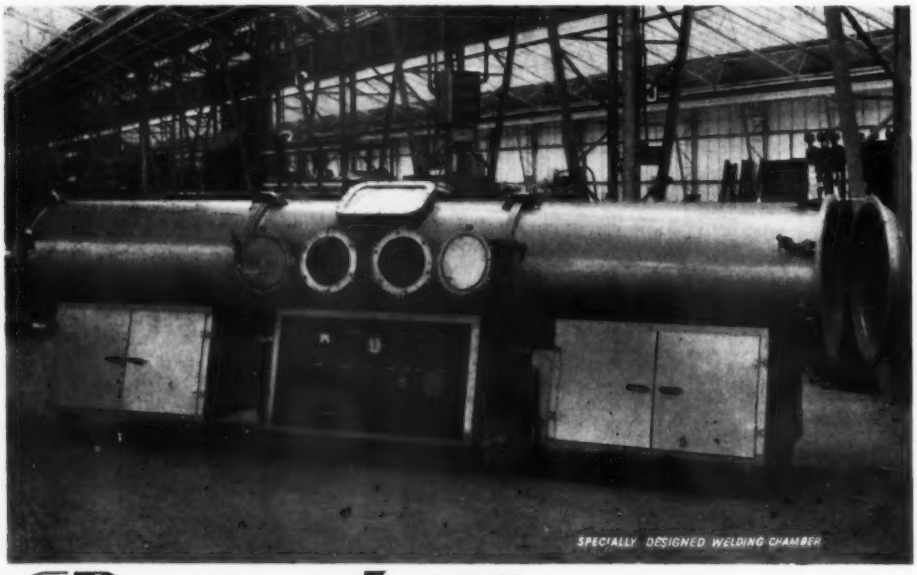

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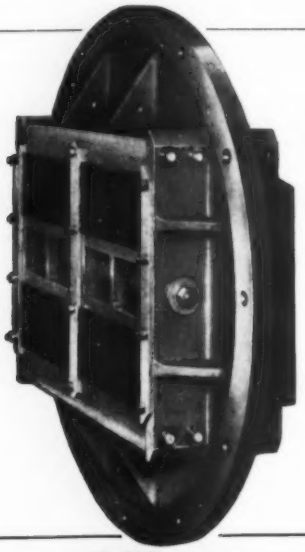

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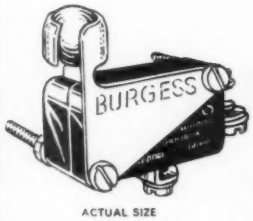

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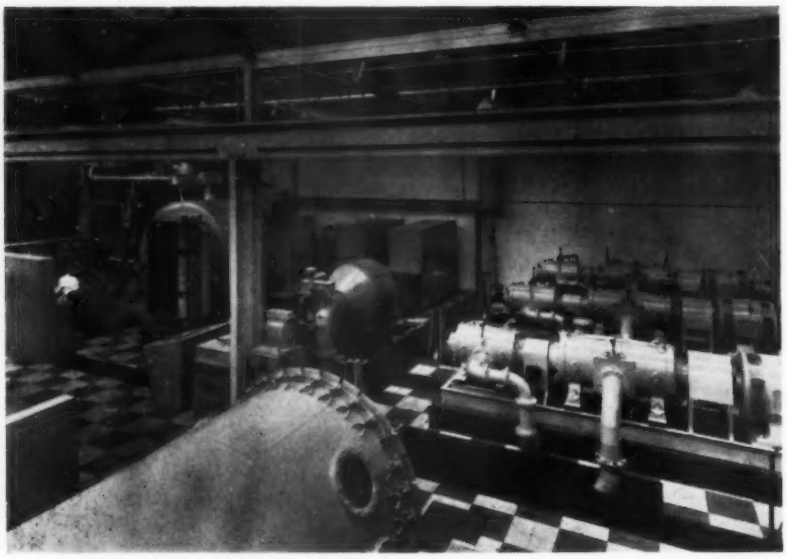

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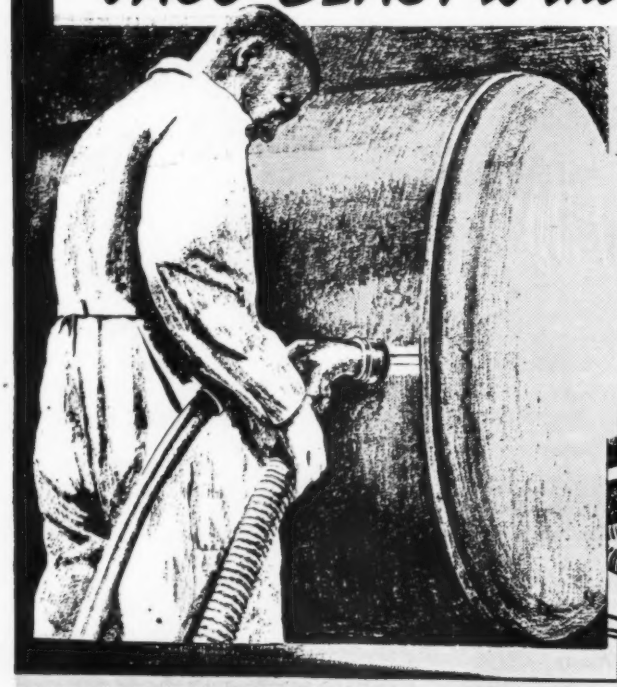

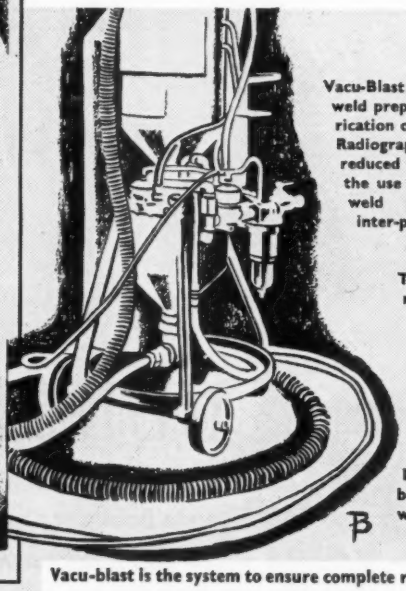

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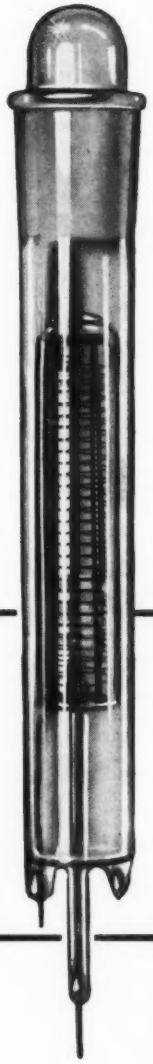

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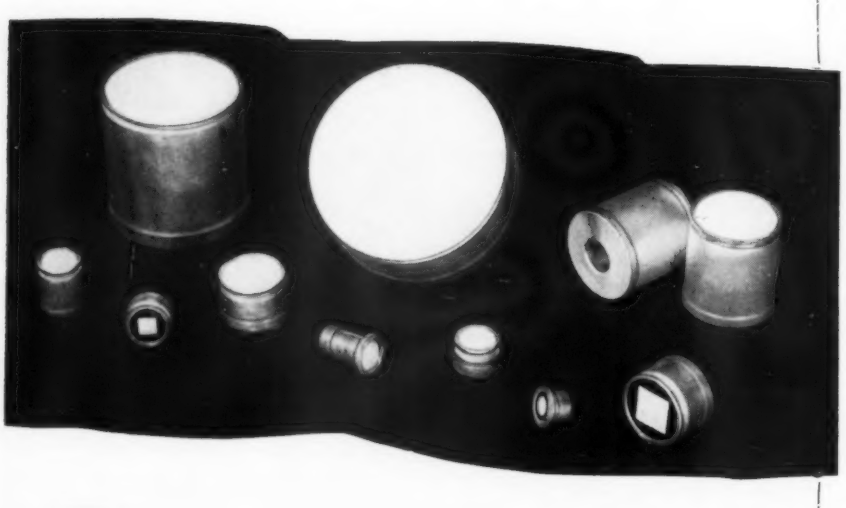

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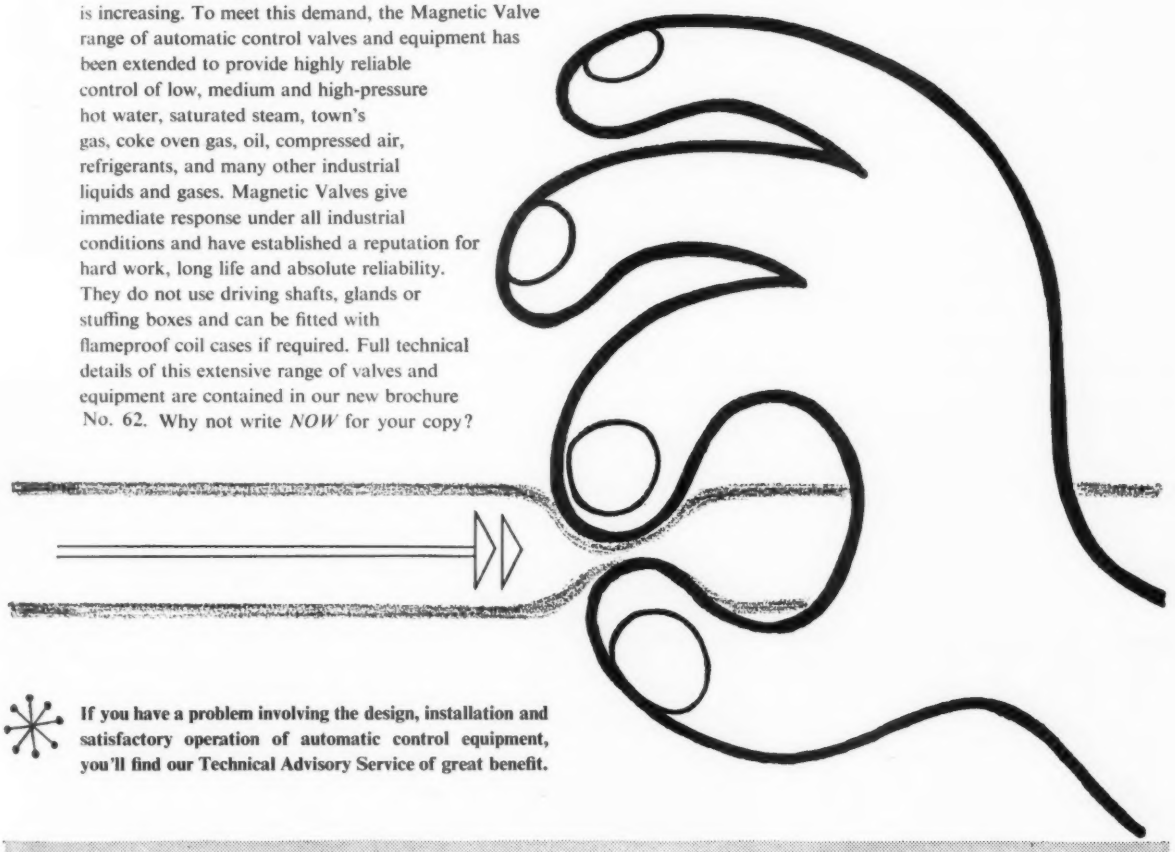

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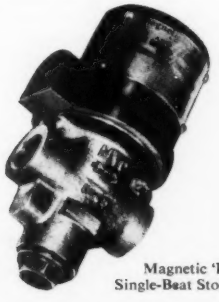

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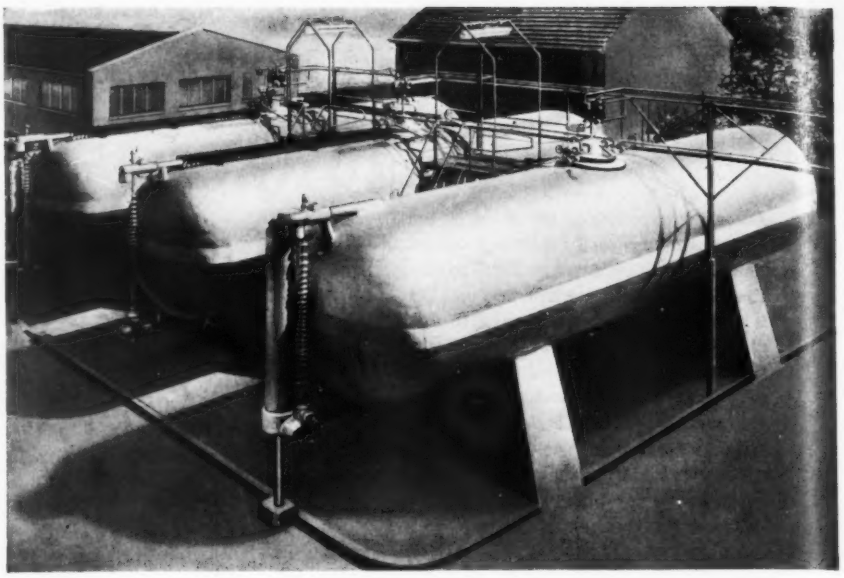

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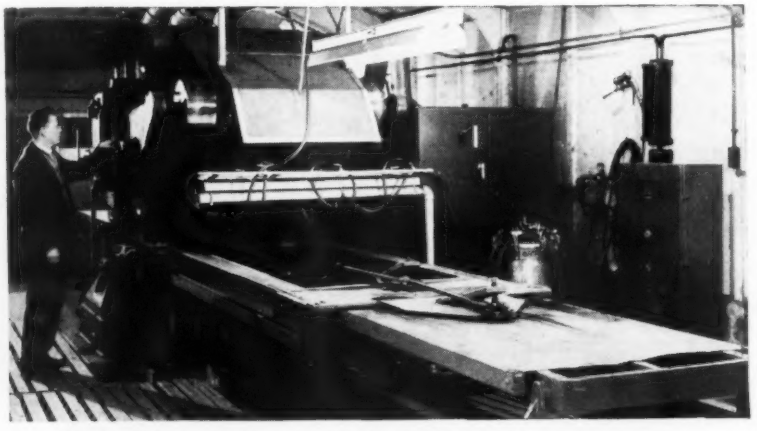

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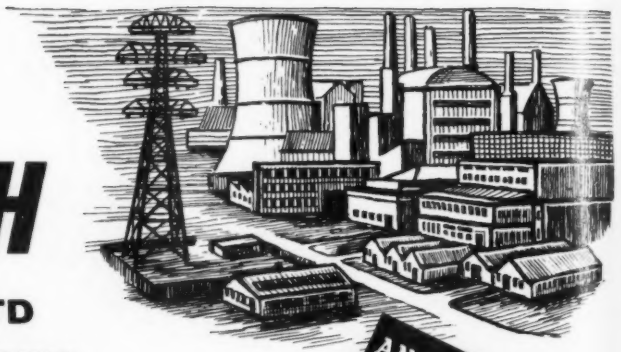

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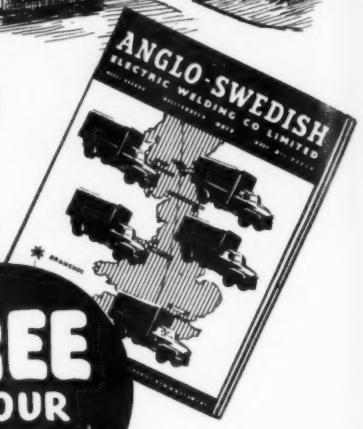

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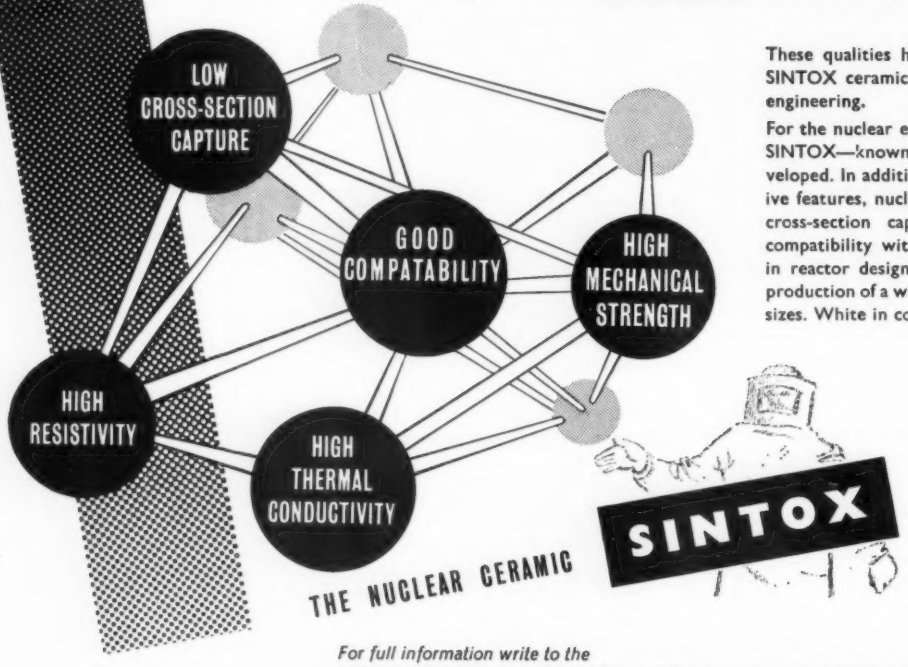

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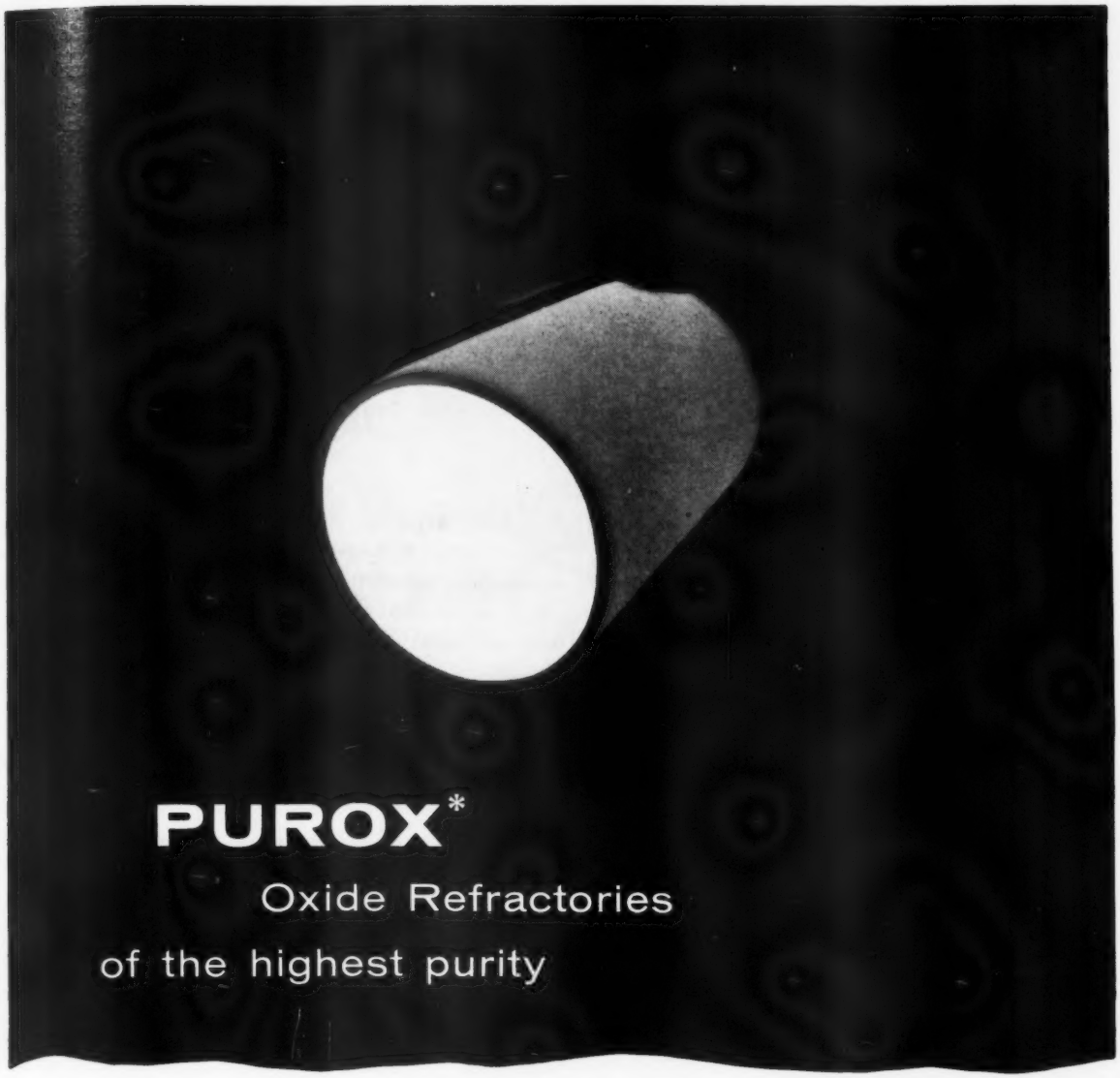

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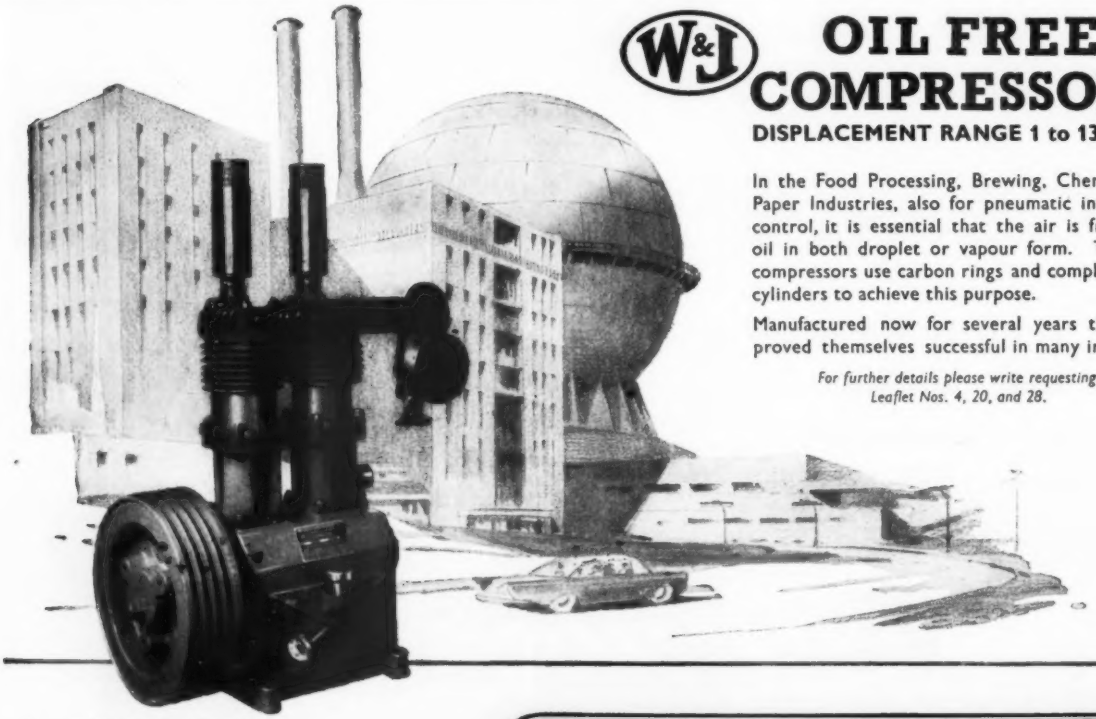

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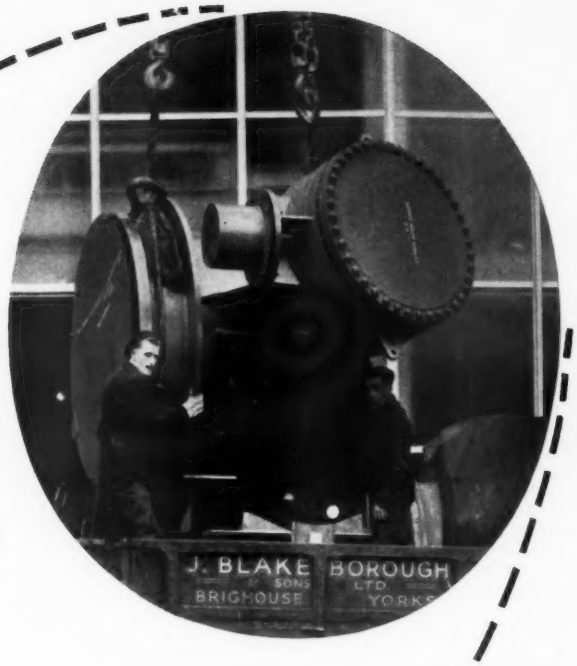

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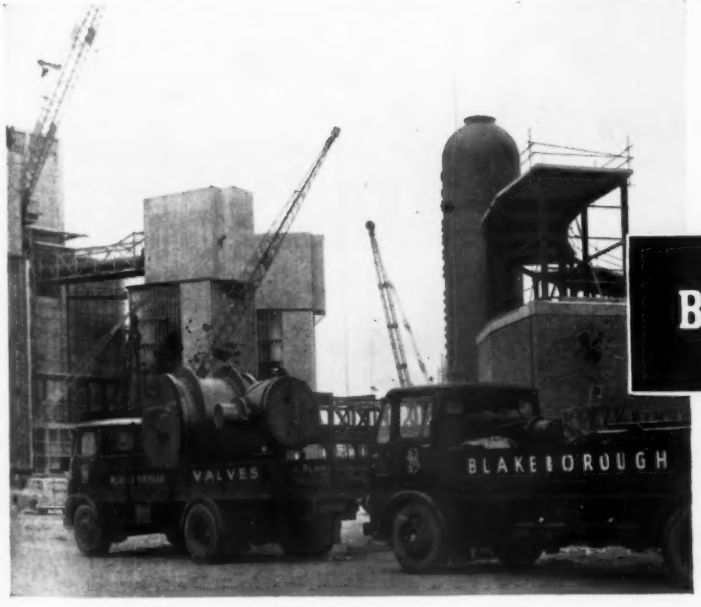

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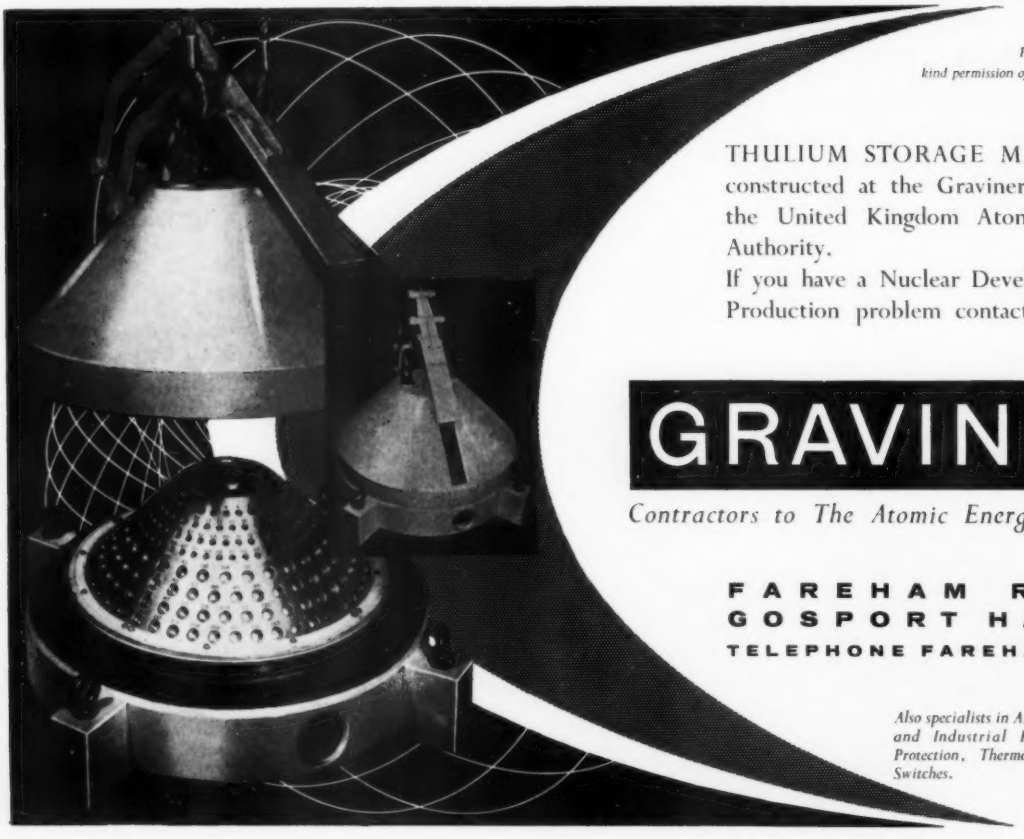

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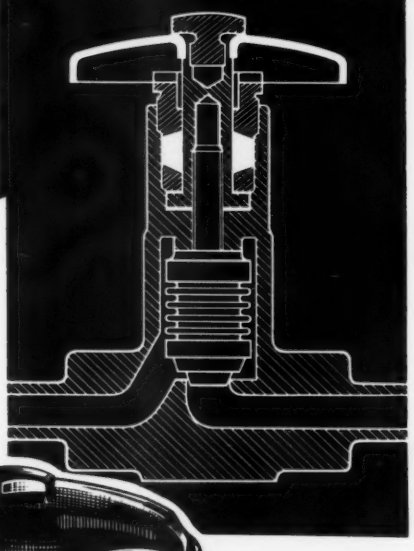

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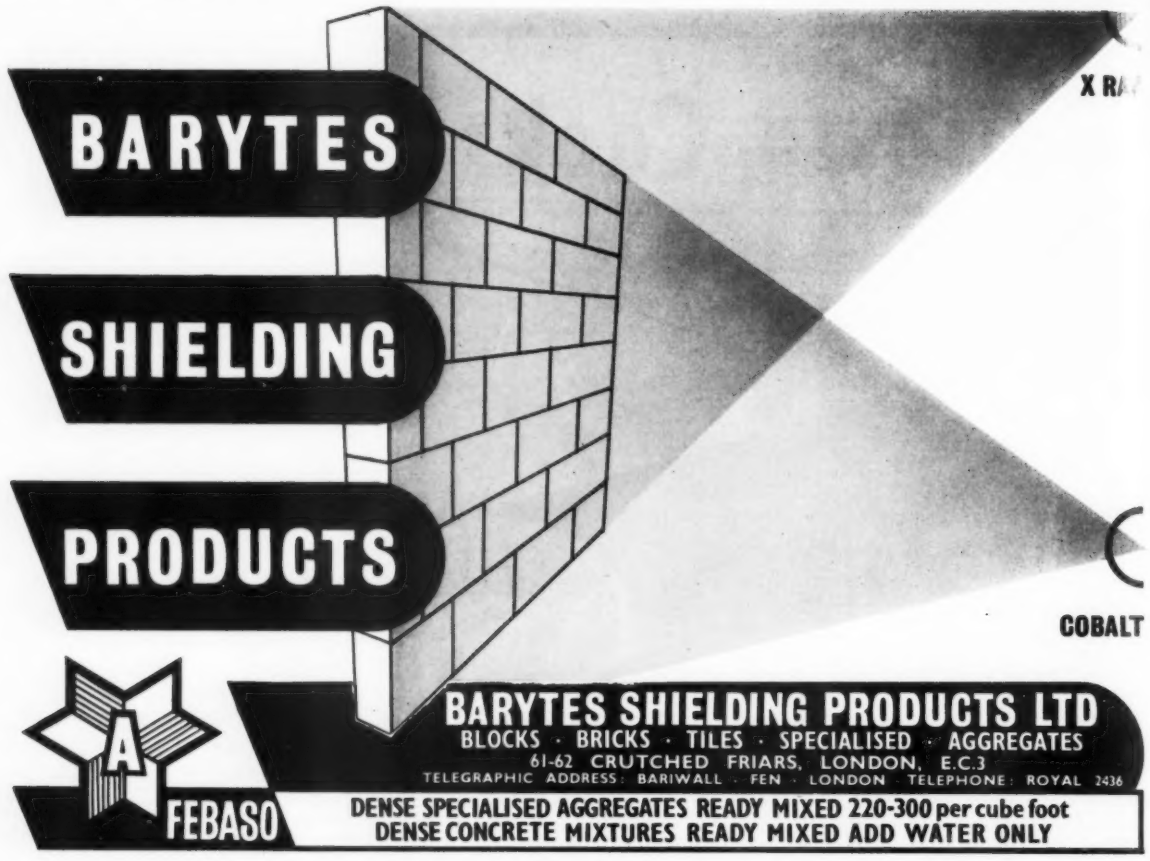
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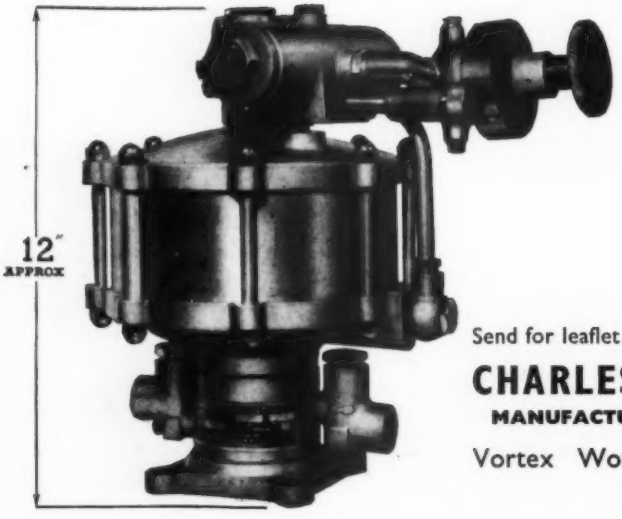

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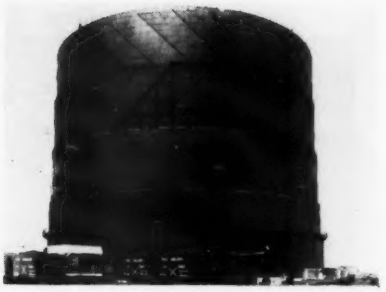

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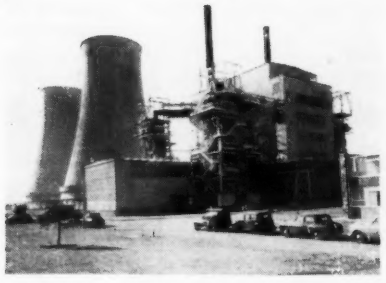

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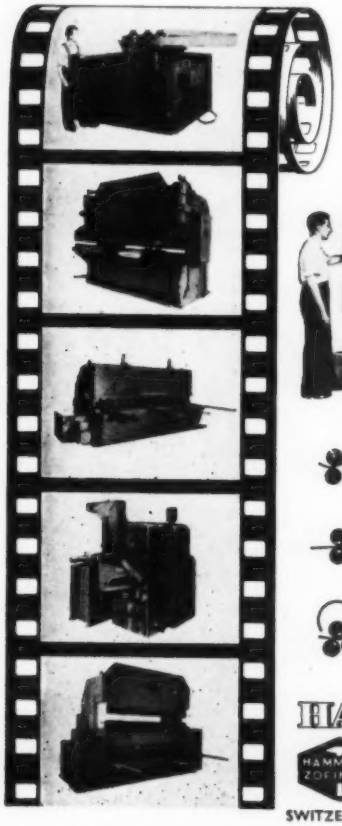

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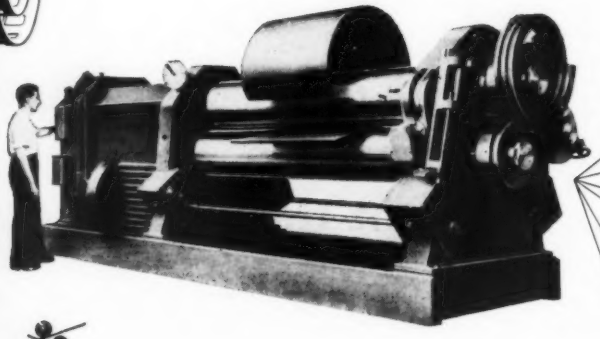

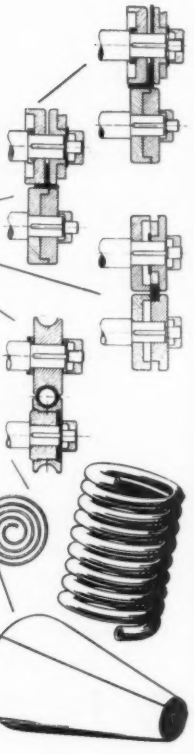

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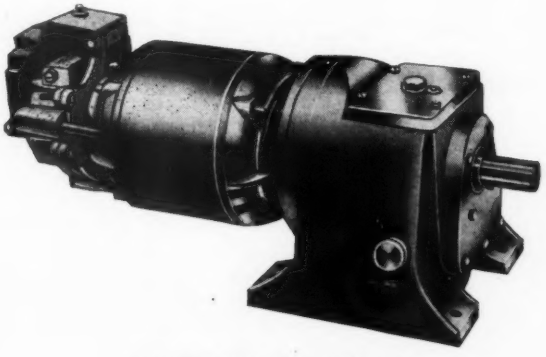

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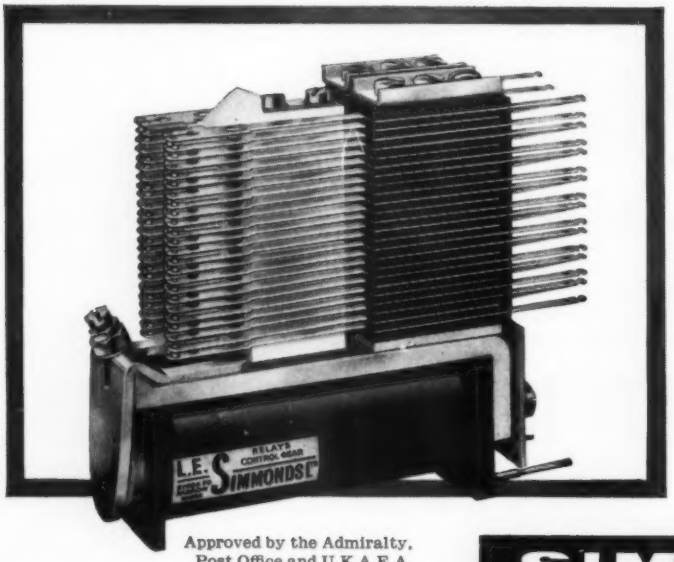

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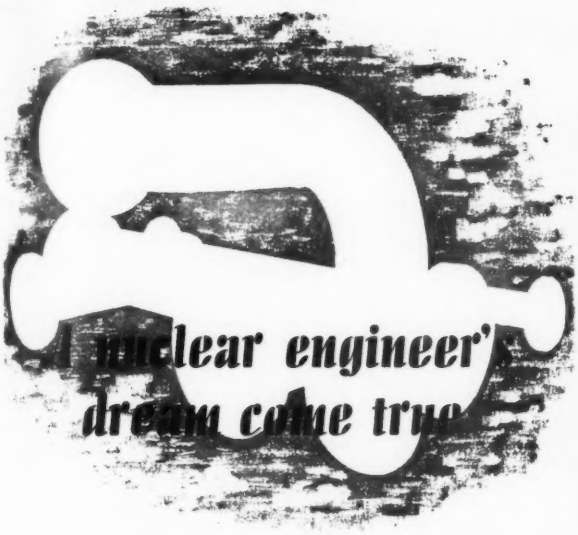

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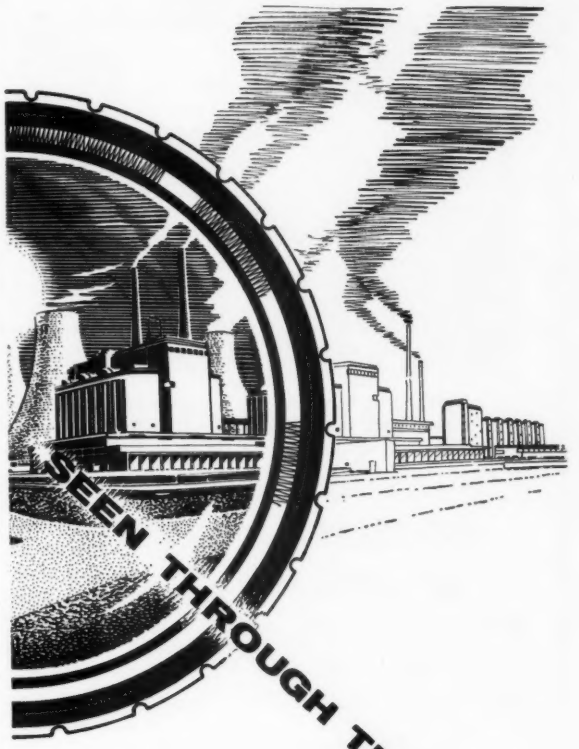

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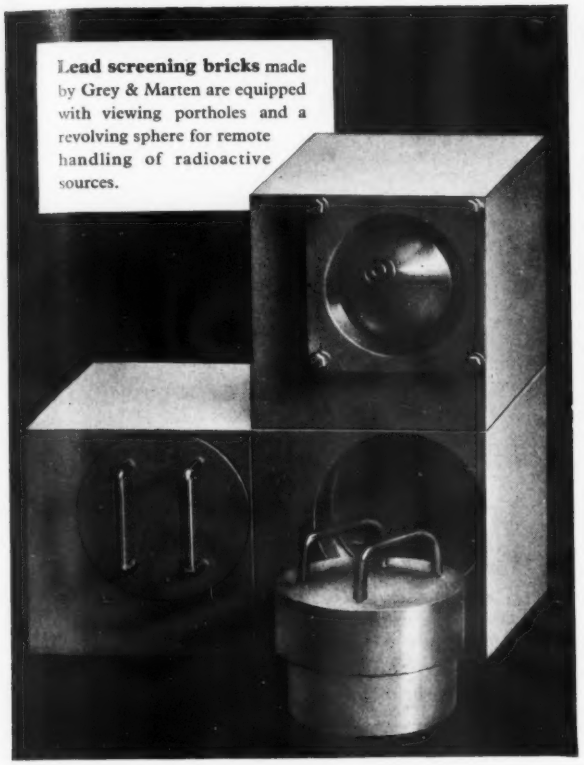

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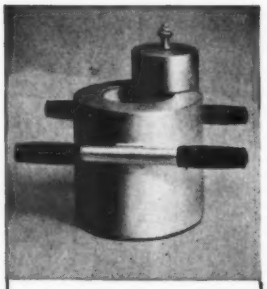

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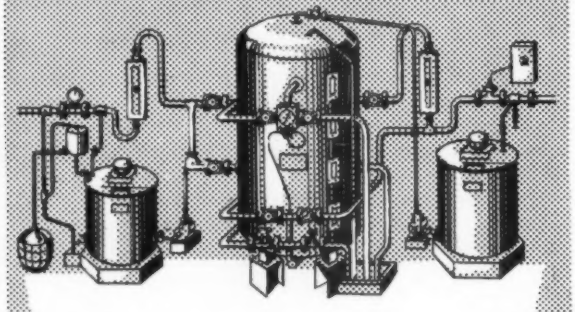

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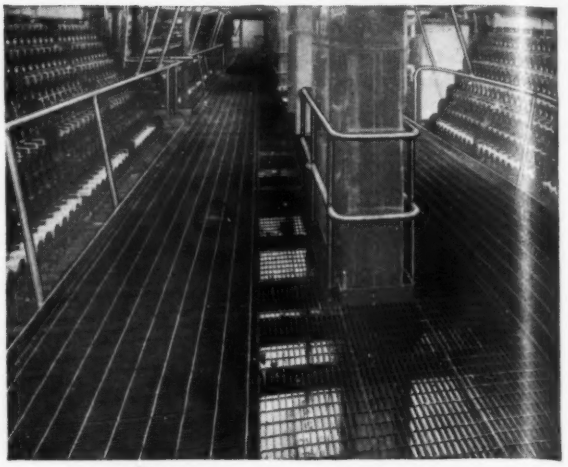

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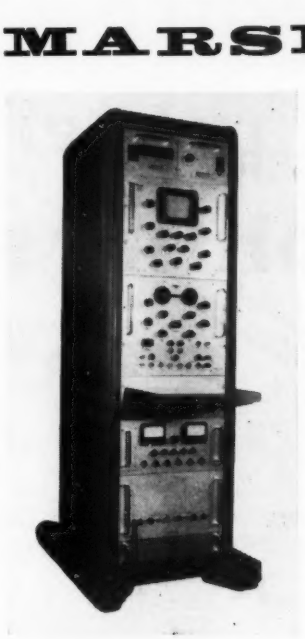

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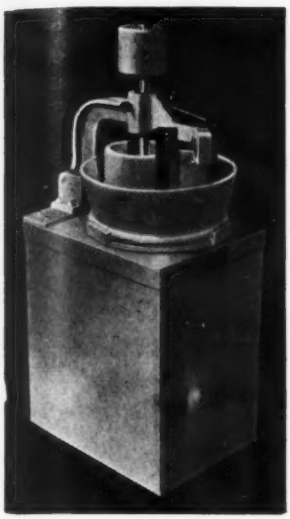

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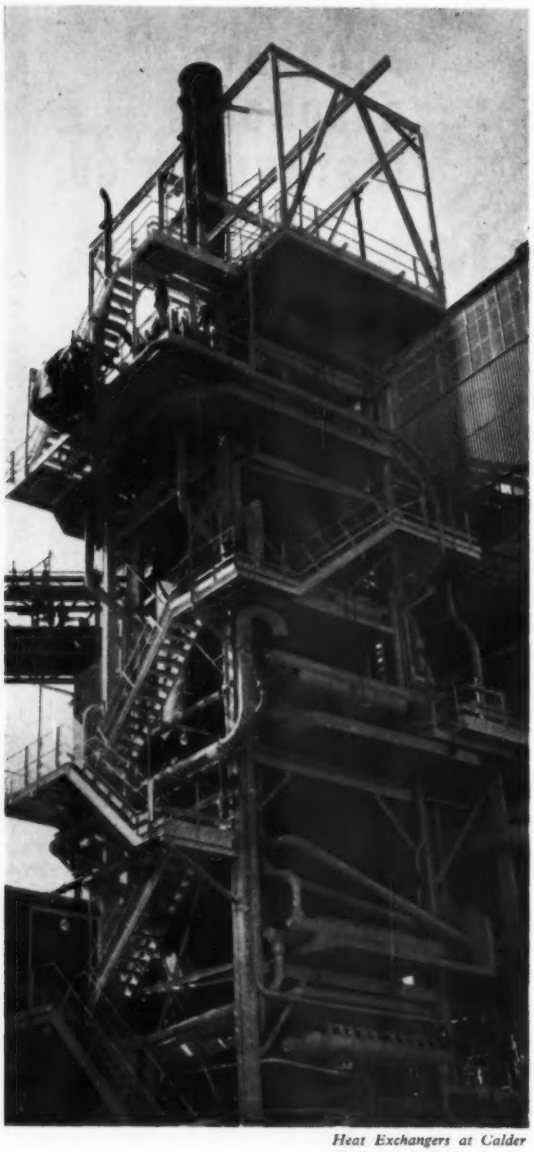

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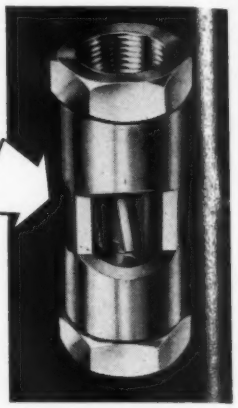

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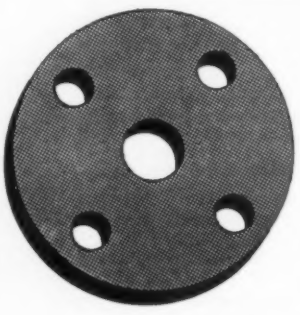

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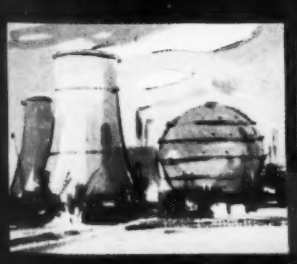

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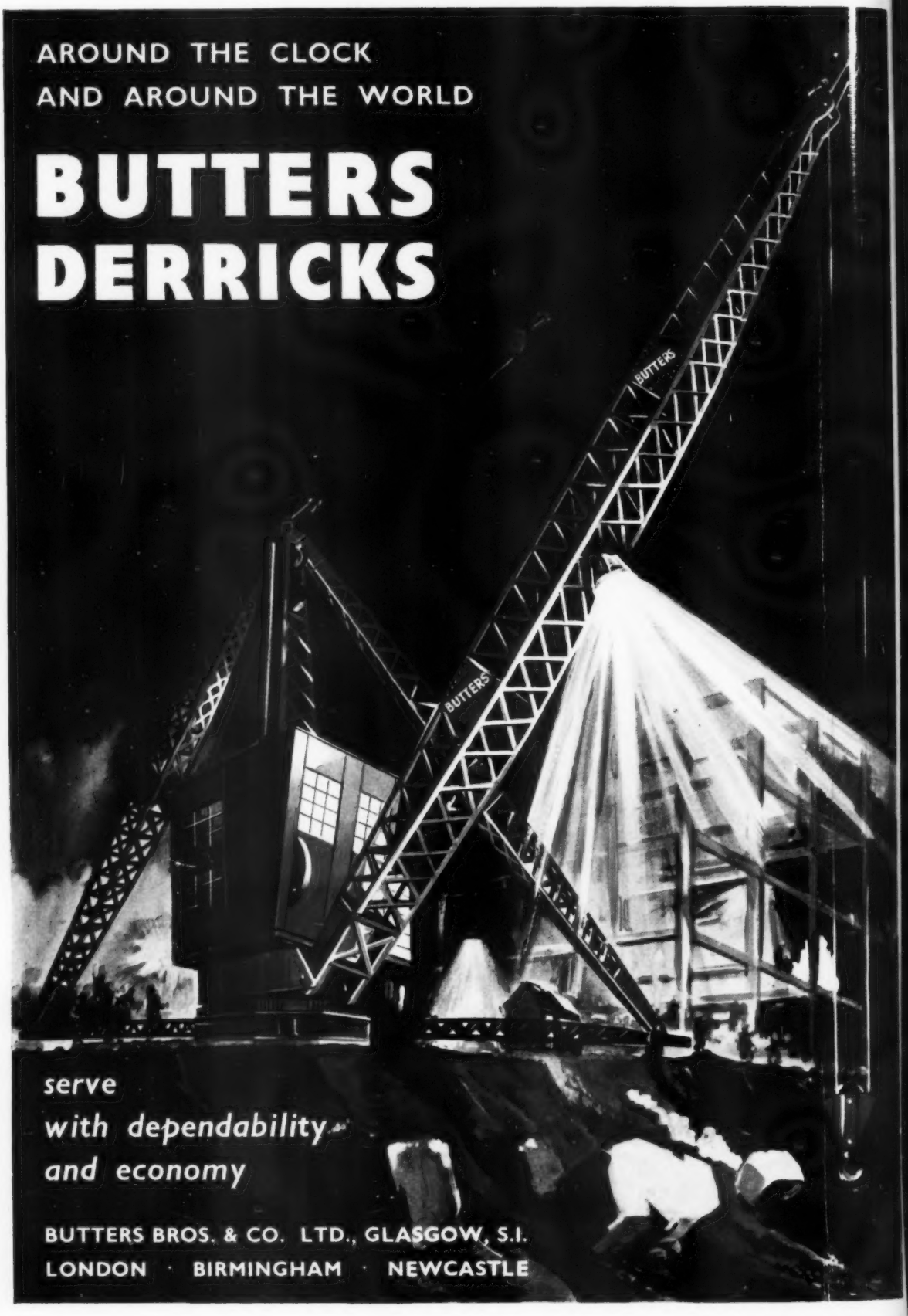

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